BRIDGING THE GAP: THE U.S. MOVE FROM RESEARCH TO OPERATIONAL NWP

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1. INTRODUCTION

12 August 1952: "Electronic 'Brain' Planned to Forecast the Weather" proclaimed a Science Service article in the *Boston Daily Globe*. Despite the tone of the article, the realization of computer-generated forecast weather maps in the United States was still three years away. Meteorologists, mathematicians, and electrical engineers had been laboring at the Institute for Advance Study in Princeton, New Jersey since the summer of 1946: the meteorologists working on theory and model development within the Meteorology Project and the mathematicians and engineers developing the computer hardware and coding to run the models within the Computer Project. While both projects were under the leadership of the brilliant Hungarian-born mathematician John von Neumann, it was the meteorologists led on-scene by Jule Charney, prodded off-site by Carl-Gustav Rossby, worried about by Francis W. Reichelderfer at the Weather Bureau, and funded by Navy and Air Force research monies that pulled off the greatest achievement in twentieth century atmospheric science: numerical weather prediction. Six years after their rocky start, they were ready to take the plunge into operational weather forecasting. The question: could the Weather Bureau, Naval Weather Service and Air Weather Service successfully work together to bridge the gap between research and operations?

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2. NWP: JUST A GLIMMER IN '45 AND '46

The success of numerical weather prediction depended upon the availability of three critical elements: sufficient surface and upper air data, physics- and mathematics-savvy meteorologists, and an electronic digital computer. Observation stations had been greatly expanded due to the needs for aviation forecasts during World War II. Likewise, the war had seen a monumental increase in the number of meteorologists – the numbers mushrooming from a little over 400 professionals in the United States to over 7000 newly minted meteorologists with physics and mathematics backgrounds who had been trained by Rossby and the University Meteorological Committee. The third critical piece – an adequate electronic computer – was in the works. John W. Mauchly and J. Presper Eckert of the University of Pennsylvania's Moore School had started building ENIAC (Electronic Numerical Integrator and Computer) in 1943 while under contract to U.S. Army Ordnance.

Indeed, in April 1945 as the finishing touches were being put on ENIAC, Mauchly paid a visit to the Weather Bureau's Washington headquarters to ascertain the possible meteorological uses of high speed sorting and computing devices. Mauchly

met with Assistant Director for Scientific Research C. F. Sarle, who told Mauchly that such a machine would certainly be useful for sorting the backlog of climatological data they had on punched cards. And it could also be useful if it could extrapolate the patterns on weather maps to create a forecast weather map. Mauchly was not sure if his new computer – dubbed EDVAC – would be able to extrapolate weather maps, but, he told Sarle, it would be able to solve partial differential equations. Would that be a help? Sarle was not interested. Burdened by increasing demands and a shrinking manpower base, he was primarily interested in controlling the vast mounds of data rolling in.

Mauchly's next stop was the Air Weather Service. There he received a much warmer reception from former and returning Weather Bureau meteorologist, Major Harry Wexler. An enthusiastic Wexler steered Mauchly to some weather officers working on a variety of meteorological problems. They immediately sensed an application to the forecasting problem – *the* major problem for both the military and Weather Bureau. Upon Wexler's return to the Bureau at the end of 1945, he would vigorously pursue this new technology.[1]

Mauchly was not a lone wolf trying to convince the Weather Bureau of the possible uses of the computer for meteorological purposes. Russian-born physicist Vladimir K. Zworykin (1889-1982) of the Princeton RCA Laboratory also envisioned meteorological applications. The inventor of the electronic-scanning television camera, Zworykin was involved with the development of meteorological instruments at RCA and had become enamored of meteorological problems including, perhaps, the ultimate meteorological problem: weather control.

Reichelderfer first heard of Zworykin's proposal for the use of "modern electronic devices" in meteorological analysis during a September 1945 visit to the RCA Lab. Intrigued, upon his return to headquarters he wrote Zworykin, requesting a copy of his forthcoming written proposal.[2] Reichelderfer was not the only person interested in Washington. So was National Bureau of Standards Director E. U. Condon (1902-1974). Condon suggested that Standards and the Weather Bureau cooperate on work with electronic computers. As Reichelderfer noted on the letter he had received from Condon, they should not "take lightly" Zworykin's proposal, even if it were unproven.[3] Indeed, Reichelderfer invited Zworykin to come to the Weather Bureau for an in-depth discussion on the use of electronic computers in meteorological analysis.[4] While that letter was en route, Condon suggested that they should ask John von Neumann to come too.[5]

The meeting, set for 9 January 1946, would include meteorologists from the Weather Bureau and the military weather services, as well as Bureau of Standards representatives. They would use this opportunity to discuss the "ways and means for improving the techniques of weather analysis and forecasting…"[6]

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[1] John W. Mauchly, "Note on Possible Meteorological Use of High Speed Sorting and Computing Devices," 14 April 1945, copied by F. W. Reichelderfer on 24 January 1946 and marked "Confidential." (Harry Wexler papers, Library of Congress Manuscript Division, B2, F1945) [Hereafter **Wexler papers**].

[2] Reichelderfer to Zworykin, 4 December 1945 (Wexler papers, B2, F1945).

[3] Reichelderfer notation on letter from E. U. Condon to Reichelderfer, 26 November 1945 (Wexler papers, B2, F1946).

[4] Reichelderfer to Zworykin, 4 December 1945 (Wexler papers, B2, F1945).

[5] Reichelderfer to Sarle, 4 December 1945 (Wexler papers, B2, F1946).

[6] Reichelderfer to von Neumann, 29 December 1945 (Wexler papers, B2, F1946).

Meanwhile, the Navy's Office of Research and Invention (ORI, later the Office of Naval Research) was expressing interest in funding von Neumann's machine. Meeting with Institute for Advanced Study Director Frank Aydelotte, ORI personnel were "very enthusiastic" about the new computing machine. Their "purely scientific" interest came with a commitment to make a substantial "no-strings attached" contribution to the effort.[7] The money may have come without strings, but it is highly doubtful that ORI's interest was "purely scientific." Military patrons do not provide money without some idea that they could ultimately benefit from the investment.

A well-placed Navy "leak" to *The New York Times* blew the possibility of a weather-predicting computer out into the open within two days of the Weather Bureau-brokered meeting. Sources were quoted as saying that there had been discussion of a new super calculator that would not only be able to predict the weather, but would make it possible to "do something about the weather" by using "counter-measures" against unfavorable conditions. Navy meteorologists thought sufficient theory existed, but the complicated calculations could not be solved quickly. The new computer would eliminate that problem. The *Times* reported that some scientists thought that the threat of tornadoes, hurricanes, and other severe weather could be reduced with advance knowledge. For example, atomic energy (i.e., nuclear weapons) might be used to divert hurricanes away from populated areas.[8] The Weather Bureau was interested in analysis and forecasting applications. The Navy, which heretofore was only involved in the funding the computer, seemed to emphasize the weather control aspects of Zworykin's proposal in its off-the record comments.

The January 9 conference participants, Reichelderfer in particular, had thought the conference was "confidential" and were very unhappy with the *Times* coverage.[9] The War Department's Ordnance Research Office actually thought the newspaper content violated military security. Perplexed, Zworykin could not understand why the Navy released the information without consulting anyone.

The "why" of the Navy leak almost certainly was related to mustering support among the Navy brass for developing a meteorological application for von Neumann's computer. Navy meteorologists, like their Weather Bureau and Air Force counterparts, realized that the computer had the potential to do two things for them: speed up the availability of predictive charts and increase their accuracy. This new tool would allow on-site forecasters to spend more time on actual weather prediction. For the military war fighters, weather was only an issue when it got in the way. When it was not a problem, no one gave it a second thought. To assure continued support from the "battleship admirals," the meteorologists would need something more appealing than faster forecast. Weather control, with its possible application as a weapon, was clearly very appealing.

Though ruffled and embarrassed by this unanticipated public relations fiasco, Reichelderfer continued to pursue the possibilities that electronic computing might offer. Wexler visited Zworykin and von Neumann in Princeton to discuss the issue. Having no meteorological background, von Neumann needed advice on the

[7] Frank Aydelotte to von Neumann, 29 December 1945 (John von Neumann papers, Library of Congress, Manuscript Division, B12, F1) [Hereafter **von Neumann papers**].

[8] Sidney Shallet, "Weather Forecasting by Calculator Run by Electronics is Predicted," *The New York Times*, 11 January 1946: 12.

[9] Reichelderfer to Zworykin, 11 January 1946 (Wexler papers, B2, F1946).

mathematical and physical requirements that had to be considered.[10] So did Mauchly and Eckert, both convinced that an ENIAC-like machine could forecast the weather "once specifications were laid down by meteorologists."[11] Therein lay the difficult part – neither electronic engineers nor meteorologists could answer this question: "How can the electronic computer be applied to meteorology?"[12] Until they established the extent of the meteorological problem they would be unable to establish the specifications for the new computer. The Air Weather Service staff wanted to know if Wexler had any ideas other than a reconstruction of the Richardson method. Lewis Fry Richardson's (1881-1953) World War I-era attempt at numerical weather prediction was to solve the so-called "primitive equations" of the atmosphere by making one 6-hour time step and doing all the calculations by hand. He published his results, a huge failure, in his book *Weather Prediction by Numerical Process* in 1922.[13] Although briefly considered as a point of departure in 1946, it was quickly abandoned.

After meeting with Wexler and others in early February, von Neumann turned to Rossby for advice. Visiting von Neumann in Princeton, Rossby shrewdly viewed von Neumann's new-found interest in theoretical meteorology as a potentially huge asset to meteorological progress. Reporting back to his friend Reichelderfer on the substance of the meeting, Rossby suggested that they needed to find a "small and versatile" group of theoretical meteorologists that would provide the foundation for this computational approach.[14]

Ultimately, Rossby recommended that the Institute for Advanced Study reach an agreement with ONR for funding a small group to attack the meteorology problem as an adjunct to the computer project. Reichelderfer strongly backed the proposed project, even though he was well aware that there was no guarantee of useful results. While preferring that the Weather Bureau should be the governmental organization to take leadership, he was realistic enough to acknowledge that financial constraints might require interdepartmental cooperation. He told Rossby that he was putting together a plan with the enthusiastic Harry Wexler in the near future and hoped that Rossby would continue to provide advice.[15]

To help the project along, Rossby negotiated a tentative contract proposal and funding arrangements with ORI staff meteorologist, Lieutenant Commander Daniel F. Rex, and then provided von Neumann with a draft proposal.[16] The proposed starting date: 1 August 1946.

The Institute for Advanced Study signed the contract with ORI on 8 May 1946. However, it took a while to get started. Manpower was a problem. Most academic meteorologists were eager to get back to work on their own research agendas that had been placed on hold because of the war. The initial group of Meteorology Project members consisted of Paul Queney, Albert Cahn, and Gilbert Hunt. Harry Wexler, while remaining in Washington, D.C., was the assigned project leader. By the end of the year, they were joined in

[10] H. Wexler and Jerome Namias to Reichelderfer, 8 February 1946 (Wexler papers, B2, F1946).
[11] H. Wexler and Namias to Reichelderfer, 26 February 1946 (Wexler papers, B2, F1946).
[12] Reichelderfer to Secretary of Commerce Henry A. Wallace, 18 February 1946 (Wexler papers, B2, F1946).
[13] Gilbert Hunt to H. Wexler, 18 March 1946 (Wexler papers, B2, F1946).
[14] Rossby to Reichelderfer, 16 April 1946 (von Neumann papers, B15, F7).
[15] Reichelderfer to Rossby, 24 April 1946 (Wexler papers, B2, F1946).
[16] Rossby to Rex, 23 April 1946 (Wexler papers, B2, F1946. Rossby to von Neumann, 23 April 1946 (Wexler papers, B2, F1946).

Princeton by AAF Lieutenant Philip D. Thompson.

Over the next few months, all of the members except Thompson would drop out of the project. He was joined by Jule Charney – newly returned from a year in Norway – and Norwegian Arnt Eliassen in the summer of 1948. Between 1948 and 1952, a number of Scandinavians (Ragnar Fjörtoft, Bert Bolin, Ernest Hovmöller, Roy Berggren), Americans (Joseph and Margaret Smagorinsky, John Freeman, Norman Phillips), and a Briton (Thomas V. Davies) moved in and out of the Project for several months at a time. Others – including Rossby – came for shorter periods.

The Meteorology Project members had been successful in running both barotropic and baroclinic models. The first ENIAC "Expedition" of March 1950 – a major milestone in the history of the atmospheric sciences – produced two twelve-hour and four twenty-four hour forecasts from initial observed data.[17] The success of the first ENIAC runs gave project members a much needed morale boost. A second ENIAC expedition took place in May 1951 because von Neumann's computer was not yet ready. Information gathered from model performance was factored into revised models and the project members continued to press on in Princeton.

Meanwhile, Philip Thompson – transferred to the Geophysical Research Directorate in Cambridge, Massachusetts, was working on models of his own. And in Stockholm, Rossby and his group – including Americans Chester and Harriet Newton, and Navy officer Bill Hubert, and the Weather Bureau's Phil Clapp – were also developing models.

Despite chronic personnel shortages, the Meteorology Project was still able to make significant gains between the time of the first ENIAC expedition and the period just following the testing of the new Princeton machine in the spring of 1952. Models were tried, compared against analyzed data provided by either the Stockholm group or the Weather Bureau analysis center, and then modified for the next run. Both barotropic and baroclinic models were checked out, as were models in two, two and one-half and three dimensions. But as Rossby had long maintained, to sell the meteorological community on the effectiveness of numerical weather prediction, and simultaneously advance model development, the Meteorology Project members would need to put their models on the line – the operational line.[18]

3. THE OPERATIONAL DECISION

By the summer of 1952, it was clear that the move into operational NWP would happen sooner rather than later. While Charney and von Neumann had just assumed that any operational group would be "joint" – just as the Meteorology Project had been a joint venture of the Weather Bureau, Navy and Air Force – Phil Thompson at GRD was just as confident that the Air Force could handle operational NWP just fine on its own, by using Thompson's models.

Seeking to forestall an Air Force monopoly in the operational arena, Charney and von Neumann, with the help of Reichelderfer, called a short-fused meeting at Princeton for 5 August 1952.[19] Weather Bureau, Air Force and Navy representatives all attended – Thompson, however, did not. He did send a point paper stating his position.

After reviewing the progress made in NWP thus far, von Neumann made

[17] For details, see Platzman (1979).

[18] Harper (2003).

[19] Reichelderfer to R. O Minter (Navy) and Thomas S. Moorman (Air Force) of 29 July 1952. (Wexler papers, B5, F1952-1).

"inferences" based on what the Princeton group had learned. He assumed a general baroclinic model providing a forecast of at least 36 hours would be the first practical forecast. HE noted that there would be three basic steps to any such forecast: (1) input, (2) actual computing, and (3) output. All of this should take 12 hours to complete. When programmed for speed considerations, he anticipated that it would take four hours to do the actual computations. Most of the other eight hours would be tied up with inputting the data.

Furthermore, von Neumann envisioned two problems that would need to be overcome: education and technology. The first was a problem because there were very few people who had both the synoptic meteorology and mathematics background to supervise and operated the program. With an intense training program, he thought they could get people trained in about three years. Technology problems included having a machine that was in "perfect condition" and in working order at any time. Sverre Petterssen (from the Air Force) noted that the machine would be "idle" most of the day, but that the "idle" time would be required for maintenance. Von Neumann anticipated that one third of the day would be devoted to preventive maintenance, one-third to test runs, and the rest for both operational and research runs.

Another discussion point concerned geographic coverage. Von Neumann thought that available machines could cover the United States, but even that would not be optimum for the 36-hour forecast He argued that it would be best to show that NWP was viable before requesting the increased amounts of data that would be required. The machine could only handle so much data due to memory limitations. If they extended the area to range from Japan to Eastern Europe – a four-fold increase – then they would need a much larger machine. A sufficiently big machine *might* be available in five years.

The Weather Bureau representatives (Wexler and Smagorinsky, who was also working at Princeton) commented that it took seven hours from data receipt to facsimile transmission of the prognostic chart with current subjective methods. A question that went unasked, but probably thought, was "How does it improve the situation to take an additional five hours to get the product out?" Wexler reported that Weather Bureau forecasters valued numerical weather prediction for time periods beyond 36 hours because they could already produce sufficiently accurate products for the 24 to 36 hour range. However, the general group consensus was that it was "too early" to lead people to think that longer range forecast reliability would be improved. Charney also argued that the barotropic forecasts, as then run, were not as good as a subjective forecast, but preliminary work on baroclinic models showed a promise of improvement.[20]

Thompson, writing in his point paper, argued for a parallel group that would use a two-dimensional model. He claimed that is was "wasteful" to pursue a three-dimensional model of the atmosphere when his two-dimensional model worked just fine. With a modest investment, they would be able to turn his two-dimensional model into an operational model suitable for routine uses. Thompson maintained that "immediate military needs," which were distinct from the needs of the populace at large or of the research interests of the scientific community, dictated that they work on a model (his) that would be operational in two years or less. Thompson's would be a short-range program to produce the best model

[20] Minutes of the meeting held at the Institute for Advanced Study, 5 August 1952 concerning practical numerical weather forecasting (von Neumann papers, B15, F4).

within two years for military purposes, while a long-range program pursuing the best possible model could still be undertaken for general use.[21] Short of two dismissive comments by Charney and von Neumann, there was absolutely no recorded discussion of Thompson's proposal.

In the end, the attendees of the Princeton meeting only agreed on a few issues. Each service representative volunteered to provide a "trainee" to Charney's group. The Navy representative expressed support for a joint venture along the lines of the Weather Bureau-Air Force-Navy (WBAN) analysis center. The Air Force representative declined to comment on the joint venture and indicated that Air Force would continue its own project at GRD while supporting the Meteorology Project as it had done in the past.[22] In the meantime, model development would continue at the Meteorology Project.

4. PROBLEMS, PROBLEMS, PROBLEMS

"Electronic 'Brain' Planned to Forecast the Weather." Just one week after the 5 August 1952 meeting that set in motion the transition from developmental to operational numerical weather prediction, *The Boston Daily Globe* ran a Science Service article describing how computers would be making Weather Bureau forecasts in "two to three years." Although still experimental, the Weather Bureau planned to use numerical weather prediction operationally by feeding current data into complex formulae and getting out eight charts every twenty-four hours. "These will represent eight horizontal slices of the atmosphere, beginning at sea level and extending up to about 13,000 feet."[23] That statement must have been a huge shock to everyone even remotely involved with the Meteorology Project. They had concentrated on producing a 500 mb chart alone. Moreover, a model that topped out at 13,000 feet (the 500 mb "steering level" is at about 18,000 feet) would not do anyone much good.

And so the race for operational numerical weather prediction was on. This was a race in which the Weather Bureau very much wanted to participate and come out a winner. Reichelderfer immediately took steps to ensure that his agency would be prepared when the models and the computers were ready. The Navy, as personified at this stage by Rex, wanted to make sure that the joint plan went forward as had been discussed at the August 1952 meeting. That meant bringing the matter to the attention of the Joint Meteorological Committee (JMC) under the Joint Chiefs of Staff. Within a short period of time, an *ad hoc* committee would be up and running, making recommendations to the JMC that would move the joint project forward. The Air Force, while continuing its investment in Thompson's Cambridge group, kept its hand in too.

Meanwhile, in Princeton, the Meteorology Project redoubled its efforts to make sure that an operational model was ready to go. However, that meant getting enough synopticians on the staff to perform the analyses critical to determining the efficacy of the models as they tested them. It

[21] P. D. Thompson, "Statement to the Conference on Numerical Prediction to be held at Princeton," 5 August 1952 (Jule Gregory Charney papers, MC 184, Institute Archives and Special Collections, MIT Libraries, Cambridge, Massachusetts, B16, F516) [Hereafter **Charney papers**].

[22] Wexler to Reichelderfer, 7 August 1952 (Wexler papers, B5, F1952-2). For additional information on the in-fighting the preceded the decision to go operational, see Harper (2003).

[23] "Electronic 'Brain' Planned to Forecast the Weather," *The Boston Daily Globe*, August 12, 1952. For an insider's recollection of the move from research-oriented to operational NWP and the subsequent efforts of the Joint Numerical Weather Prediction Unit, see Cressman (1996).

was also becoming apparent that there were other problems that would need to be considered: selecting a computer, handling the data quickly and efficiently, and ensuring that the data sources themselves were adequate for the models. These issues were outside the purview of the Princeton group's members since they were modelers, not data handlers. People external to the Project would need to address those issues and soon. In the meantime, Project members wanted to make sure that the promise of NWP was not oversold to the media.

And these groups in the United States were not the only ones working on NWP. Rossby's Stockholm group was working to bring the NWP project to an operational stage with the goal of running models on the Swedish Air Force's new computer, BESK. They had fewer bureaucratic hoops to jump through – would they be the first ones to get out usable prognostic charts?

This final phase would bring numerical weather prediction from a theoretical vision to an operational reality. It would involve many more people than the small Meteorology Project in Princeton. This transition would very much involve the same government agencies that had been interested from the start: the Weather Bureau and the military weather services. The final part of this story (although just the beginning of the story for numerical weather prediction) addresses themes of governmental control over scientific endeavors, the use of the media to spread an agency's message, and how scientific research can come to take a back seat to more practical issues when science moves from the theoretical to the operational realm.

4.1 The USWB Gets Started

Weather Bureau Chief Francis W. Reichelderfer had been a strong proponent of theoretically influenced methods of weather forecasting since his days as a Navy aerologist, studying and promoting the Norwegian method of analysis and forecasting. He had aggressively encouraged von Neumann to put his new computer towards the weather forecasting problem. Throughout the life of the Meteorology Project, Reichelderfer had sent Wexler, his Scientific Services Division head, to Princeton to check on progress. He had also offered the assistance of Bureau personnel in securing and analyzing data for the Project's use. Now, as a member of the Joint Meteorological Committee, Reichelderfer was in an excellent position to influence the direction of a joint operational unit manned and funded by all three weather services. Just as the analysis function had been centralized at the Weather Bureau under the joint manning and sponsorship of all the weather services, Reichelderfer would do everything possible to ensure the Bureau's position at the forefront of operational numerical weather prediction. To guarantee that he was not out-maneuvered by his military counterparts, Reichelderfer started early to create an adequate support structure within the Bureau.[23]

Joseph Smagorinsky had worked periodically for the Meteorology Project while finishing his Ph.D. during his leave from the Weather Bureau. A month after the

[23] Fuller (1990) claims it was the Air Force that was pushing for a joint numerical weather prediction unit, that Reichelderfer and Wexler did not think NWP was ready to go operational, and that the position paper presented by Reichelderfer to the JMC was actually written by the Air Weather Service in the spring of 1953. The archival evidence shows otherwise. The Weather Bureau had already started to move into operational NWP within a month of the August 1952 meeting – a meeting at which the Air Force *declined* to go operational in a joint unit. Indeed, the AWS did make overtures to other participants in the spring of 1953, but only because it feared being left out of the program. See Fuller (1990), 222 (and footnote 35).

operational NWP meeting in August 1952, Reichelderfer invited him to return to the Bureau as the head of its new "pre-operational" numerical weather prediction unit. Its purpose was to indoctrinate Bureau personnel in numerical techniques by doing limited hand computations. The unit would also recommend changes to observational methods based on anticipated data needs.[24] Smagorinsky was pleased to accept. He would join the new unit in January 1953.[25]

Since Smagorinsky had more experience with NWP than anyone else at the Bureau, he created his own job description. However, Smagorinsky was not without help in this task. Charney provided him with a detailed list of tasks that needed to be accomplished if the Bureau had any hope of being prepared to successfully enter the operational numerical weather forecasting world. The hand calculations mentioned by Reichelderfer would be focused on Fjörtoft's 24-hour barotropic forecasts, and a two-layer model to compute initial tendencies and vertical velocities. Smagorinsky would also need to direct work on determining large-scale weather elements from numerically predicted flow fields, e.g., deducing cloud formation from vertical motion. He would direct research on problems affecting both long- and short-range prediction. The Bureau would need to do much work on data acquisition and handling, including the determination of the minimum amount of required data for successful model runs, communications requirements for collecting data and disseminating forecasts, and methods of electronically checking data and performing objective analyses. Last, and perhaps most importantly, Smagorinsky needed to introduce the "philosophy, physical basis and techniques" of numerical weather forecasting to the Weather Bureau.[26] There was no guarantee that even if numerical weather forecasting did fulfill its promises that it would be an easy product to sell to the Bureau's beleaguered, marginally-paid forecasters who had limited professional training in meteorology. They were accustomed to doing all analysis and forecasting by subjective hand techniques and were not likely to look with favor upon the output from a new-fangled computer. Smagorinsky would not only need to be a masterful organizer of data, communications, and computers, he would also need to be on top of model development and a salesman *par excellence* to push this project forward.

Smagorinsky had some immediate needs for his new Numerical Forecasting Group: people and equipment. He would need at least two full-time mathematics-savvy synopticians, two part-time statistical clerks, a full-time assistant, and a "simple electronic computer." Smagorinsky would work part-time on all of their projects.[27] The requirement for personnel with both synoptic meteorology and mathematics skills was a critical one. Unfortunately there were very few people who possessed those combinations of skills – especially not people who might be willing to work for the Weather Bureau.

The Bureau had other problems besides personnel and data handling to address. In order for numerical weather prediction models to work, they needed to be kept supplied with adequate upper air sounding data – data which were much more expensive to obtain than surface

[24] Chief, Weather Bureau (Reichelderfer) to J. Smagorinsky, 8 September 1952 (Wexler papers, B32, NWP).
[25] J. Smagorinsky to Chief, Weather Bureau (Reichelderfer), 10 September 1952 (Wexler papers, B32, NWP).
[26] J. Smagorinsky to R. N. Culnan, 30 September 1952 (Wexler papers, B32, NWP).
[27] J. Smagorinsky to H. Wexler, 5 March 1953 (Wexler papers, B32, NWP).

observations due to the cost of the weather balloons, the gas to fill them, the instrument boxes that they took up into the atmosphere, and the tracking equipment to gather the data. Reichelderfer sent a memo to several of his subordinates addressing this issue. If they were going to use numerical weather prediction operationally, they were going to need not only *more* upper air soundings, but *more widely* distributed soundings. During the war, upper air stations had been installed all over the world. Indeed, it was the very availability of these upper air reports that had made numerical weather prediction possible in 1946. Unfortunately, that very expensive upper air equipment had been installed in developing countries which could not afford to operate it. Therefore, the money to keep those stations operational would need to come out of the U.S. foreign aid budget. In some places, each ascent cost one hundred (1953) U.S. dollars. With two ascents per day (one each at 0000 and 1200 Greenwich Mean Time) multiplied by hundreds of sites, that was an enormous cost. The Weather Bureau certainly did not have the money to keep them open. As Reichelderfer put it, "The belief of our military representatives in foreign countries that some way could be found to continue services at this high level of cost only reflects the lack of economic common sense that is all too prevalent." Having operated his own organization on a shoestring for years, Reichelderfer did not have much patience with his military colleagues who did not seem to recognize a money issue when it presented itself. Reichelderfer asked his people to develop ways of getting needed upper air information for considerably less money.[28]

Later in the spring, Smagorinsky visited with von Neumann and Charney in Princeton. Smagorinsky still had the same two basic worries: personnel training and data handling. The Bureau had to get ahead of the training program and make sure that it could efficiently handle incoming data for the computers or else the operational plans would never work. Thus, Smagorinsky recommended that the Bureau continue with its numerical weather prediction program as it existed, but start preparations for expansion by sending some of its employees to Platzman's ten week summer course in NWP at the University of Chicago. Platzman had been involved with the Princeton group for a number of years and knew the needs of people entering the field. His planned course would cover the logic, physical basis, and techniques of numerical forecasting. Smagorinsky argued that very few people had numerical weather prediction expertise. His goal was to ensure that the Weather Bureau maintained its perceived edge. Smagorinsky recommended that at least three Bureau meteorologists currently working in the numerical field be sent to Chicago for the course despite the tight budget situation. In a marginal note, Wexler agreed.[29]

On the data handling issue, Smagorinsky recommended that the Bureau attack this problem by pursuing the techniques and equipment for automatic data accumulation, handling, and transmission required for numerical weather prediction techniques. This idea delighted von Neumann and Charney because it provided a way to fix the thirty years' worth of "patch-work and improvisation" that had characterized the Bureau's handling of meteorological data. Von Neumann volunteered to consult on the project.

[28] Chief, Weather Bureau (Reichelderfer) to Assistant Chief, Scientific Services (Wexler) and P&PMO (Tannehill), 24 March 1953 (Wexler papers, B32, NWP).

[29] J. Smagorinsky to Chief, Weather Bureau (Reichelderfer) via Wexler, 29 May 1953 (Wexler papers, B32, NWP).

Charney suggested that Julian Bigelow, former chief engineer of the IAS computer, might also make a good consultant. Von Neumann and Charney were also interested in the objective analysis work being undertaken by the Weather Bureau. The Princeton group did not have the time, computer or otherwise, to devote to this part of the numerical weather prediction problem. That the IAS computer was going to be inoperable for the next two to six months did not help the situation.[30]

In July 1953, the Weather Bureau adopted Smagorinsky's suggestion by proposing to study the Automatic Procurement and Processing of Data (APPOD). Sounding the same tone as Smagorinsky's memo – and probably written by Smagorinsky himself – the proposal argued that current data handling was terribly inefficient. When data came in via teletype, it punched a paper tape. Instead of processing the data from the tape, the data were transferred to several other media, and the original tape was thrown out. Several suggestions followed for making the entire system, from collection to analysis, more efficient, more accurate, and less susceptible to human-introduced errors.

The data handling was not a single problem – it combined several problems starting with instrument design and ending with the dissemination of the final forecast. Unless all relevant issues were addressed, the problem would still exist. In that case, a computer could generate a forecast in a few minutes, but only after many hours had been expended trying to collect and feed in the data. Since a major selling point of NWP was its speed, failure to fix the data problems would eliminate much of its promise. Under consideration were automatic instruments including those that would take surface readings of wind, temperature, pressure, precipitation, clouds, radiation and visibility. The Army Signal Corps had worked on such instruments, designed to be placed in remote sites, during World War II. One idea for obtaining upper air sounding information from oceanic areas – a critical problem for numerical modelers – was to station automatically operated sites at sea which would serve as microwave communications relay stations transmitting the results of sounding apparatus dropped by rockets. However, given the amount of data needed – two observations per day – launching multiple rockets over an oceanic area for the purpose of dropping "dropsondes" was a very expensive solution, considering that Reichelderfer was not sure he could find enough money to keep overseas stations with land-based launching areas operational. Once collected, if data could be transmitted and received by microwave and then written directly to magnetic instead of paper tape, that would also reduce processing time. As handled at the time, data were checked and evaluated by technicians. If the computer could check and evaluate raw data observations such that spatially and temporally inconsistent data were automatically tossed out, then it could also be used to smooth out small-scale variations and allow for easier analysis and interpolation between grid points. Although this probably seemed like a good idea at the time, sometimes it turned out that the "odd" report *was the correct report*. If thrown out, the results of the run could be badly skewed. At some point a person would still need to be involved as a backup evaluator. However, machine assistance would certainly speed up the process. Once the computer had produced the new chart, forecasters would need efficient ways of getting a hard-copy. Automation needed to extend to this part of the process, perhaps with a mechanical plotting device. And once the plot had been made, the Bureau would need to get the product out to forecasting stations – ashore

[30] Ibid.

and afloat. High-speed facsimile broadcasts could be used to get the information to local forecast centers. Local forecast centers could use stored memory devices, e.g., a magnetic drum, for automatic selective broadcasts. The project had an estimated price tag of $55,800; it would fund a staff of eight meteorologists and other technical specialists. Von Neumann, Bigelow, meteorologist Athelstan F. Spilhaus, and engineer J. C. Bellamy of the Cook Research Laboratory in Chicago would be the consultants.[31]

Although the Bureau was not ready for operational NWP, it was on the right path. Smagorinsky had secured help with both training and data handling – issues that had not been on the table for the Princeton team. Now it was just a matter of making it happen both in-house and with the military weather services.

4.2 Jointly Speaking

Having a meeting and deciding to "go joint" was one thing – successfully bringing it about was another matter entirely. Such an undertaking had to involve participants who could set aside their own personal agendas and concentrate on successfully melding people, institutional cultures, equipment, spaces, and funding from different sources with a minimum of in-fighting. If the proposed joint numerical weather prediction operational center were to become a reality, those interested in making it happen would need to move early and keep abreast of the situation. The Navy had moved first.

In early October 1952, Commander Daniel F. Rex of the Office of the Chief of Naval Operations advised Phillips that he had no corrections or objections to the minutes of the 5 August meeting which had addressed operational numerical weather prediction (NWP). Even though some felt the time was not right to pursue operational NWP, the Navy intended to raise the subject through a number of "Washington committee structures." Among them were the Joint Meteorological Committee (JMC) and the Subcommittee on Aviation Meteorology of the Air Coordinating Committee (ACC/MET). The former focused strictly on government issues, while the latter represented civilian concerns as well.[32] A month later, in another letter to the Meteorology Project, Rex reiterated the Navy's intention to get a joint agreement among the Navy, Air Force and Weather Bureau concerning the organization, scope and objective for a "national numerical forecasting (or computing) center."[33]

Then in May 1953 while Smagorinsky was visiting von Neumann and Charney in Princeton, the Air Weather Service's Colonel George F. Taylor dropped by to discuss operational NWP. Recalling that the Air Force had not been an enthusiastic supporter of a joint operation during the August 1952 meeting, Taylor carefully avoided an "official" stance while quietly pressing for a joint operational group. He acknowledged the Bureau's poor fiscal situation; the military services would have to provide most of the funding. Taylor supported forming a committee under the auspices of the JMC or ACC/MET if it would have some real authority to direct action. He most emphatically did not support the establishment of a powerless advisory committee. Smagorinsky subsequently recommended to Reichelderfer

[31] Proposal for a Study Project on Automatic Procurement and Processing of Data (APPOD), Weather Bureau, 15 July 1953 (Wexler papers, B32, NWP).

[32] Rex to Phillips, 7 October 1952 (Charney papers, B14, F465 - attached to Stickles letter of 15 June 1953).

[33] Rex to Charney, 24 November 1952 (Charney papers, B14, F465 - attached to Stickles letter of 15 June 1953).

that the Bureau work toward forming an operational joint unit with the Navy and Air Force as soon as possible so that they could place an order for an IBM 701 type "high speed calculator."[34]

Within the month, the Weather Bureau acted on Smagorinsky's suggestion. The recommendation: that the JMC create an *ad hoc* committee to draft a plan for a joint operational NWP unit to be established by 1 July 1954. Since the WBAN Analysis Center already existed as a model of a joint meteorological forecasting venture, the Weather Bureau argued that it made sense to establish a similar organization for numerical weather prediction. There were so many potential fiscal, technical, equipment, and personnel difficulties, that only by working together were the three weather services likely to see operational NWP in the foreseeable future. Indeed, the Weather Bureau commented, "It has been reported that workers in Sweden, England, and Germany (W.Z.) plan to use those computers available for operational use by January 1954."[35] The possibility of being overshadowed and outperformed by European groups undoubtedly provided some impetus to get the project moving. By the middle of 1953, all the weather services were actively pushing for some kind of joint operational approach to numerical weather prediction. The next step was coming up: the establishment of what would turn out to be a series of *ad hoc* committees.

4.3 The Ad Hoc Committees

The JMC was originally established during the early years of World War II to address the provision of meteorological support during a national emergency. All of the military services and the Weather Bureau were represented. Although it could have been a problem having a civilian agency head on a military committee, it was not: Reichelderfer was a retired Navy officer, and his knowledge of military missions and requirements made him a valuable member of the JMC. His position as a JMC member also provided a venue for advocating for the new joint unit. Had Reichelderfer not been a JMC member, it might have taken more time to sell a strictly military committee on the importance of a still operationally unproven method of weather prediction.

Within two weeks of receiving the Weather Bureau's point paper on numerical weather prediction, the JMC created the Ad Hoc Committee on Numerical Weather Prediction. It was composed of representatives from each weather service and chaired by Rex, who had arranged for the original funding for the Meteorology Project while assigned to ONR in 1946. After several preliminary meetings, the Ad Hoc Committee members arranged to hold a conference at the Pentagon (where they worked) on 10 August 1953 with authorities in the numerical weather prediction field. Besides von Neumann, the committee invited meteorologists Charney, Gilchrist, Berggren, and computer engineer Bigelow from IAS.[36]

A very interested Von Neumann was, unfortunately, out of town and unable to attend the meeting. Extremely pleased that plans were moving forward, he requested copies of the minutes so he could provide comments at a later date.[37] Writing to Charney about the upcoming meeting, von Neumann expressed great pleasure in

[34] J. Smagorinsky to Chief, Weather Bureau (Reichelderfer) via Wexler, 29 May 1953 (Wexler papers, B32, NWP).

[35] Supporting Paper by U.S. Weather Bureau Member (Reichelderfer) on Numerical Weather Prediction for the Joint Meteorological Committee, 10 June 1953 (Wexler papers, B32, NWP).

[36] Rex to von Neumann, 22 July 1953 (von Neumann papers, B15, F4).

[37] Von Neumann to Rex, 3 August 1953 (von Neumann papers, B15, F4).

the "'joint' character of the enterprise." He thought it very important for the "enterprise in question" and for the future of the Meteorology Project that Charney participate – which of course he did.[38]

Less than two months after its creation, the Ad Hoc Committee had developed, with the help of its distinguished panel of consultants, a detailed plan for creating an operational numerical weather prediction unit by the 1 July 1954 deadline.[39] Four goals had to be met before opening the unit: model development, computer acquisition, personnel training, and the finding of a suitable location. The first goal had been met because of the Meteorology Project's work. Numerical output (analysis and prognosis) had shown sufficient skill (based on placement of high and low pressure systems) to make it competitive with the best subjective methods. That was a very optimistic conclusion, but one that had to be made in order to keep the project viable. Had the conclusion been that the models could not compete with subjective methods, the proposal to establish the joint unit would have quickly died. To meet the second goal, the weather services would need to secure a computer. Few computers could handle the meteorology problem in 1954 and in any case they were not available "off-the-shelf." The International Business Machines Corporation (IBM) had produced a Type 701 "electronic computer" – closely modeled after von Neumann's machine – which could be used for meteorological work. IBM could have a leased version of this machine ready by 1 October 1954. The third goal – sufficient trained personnel – had been met because the three weather services had identified enough meteorologists and meteorological analysts to serve with the Unit. The last goal – a location to house the unit – appeared to have been met based on information provided by the JMC itself. JMC advised the Ad Hoc Committee that space would be available near the WBAN Analysis Center – which had been in the decrepit Weather Bureau headquarters building, but was moving to new spaces in Suitland, Maryland in the spring of 1954.[40]

While everyone concerned agreed that it was best to "go joint," in reality military and civilian organizations operated differently. In particular, military personnel were frequently reassigned. A high turnover rate among personnel would not be advantageous to the Unit's success. Therefore, the military services involved were encouraged to extend the "tours," i.e., assignments, of their personnel for as long as possible.[41] This was a critical issue. Most military assignments were only two years long – some were even shorter. Without the tour extensions, military personnel would be leaving for a new assignment just about the time they became productive members of the team.

With the time ripe to form an operational unit that was without precedent, the Committee wanted to ensure that the

[38] Von Neumann to Charney, 29 July 1953 (Charney papers, B16, F516).

[39] Minutes of the sixth meeting of the Ad Hoc Committee on Numerical Weather Prediction held 11 August 1953. Members of the committee: Chair: Commander Daniel F. Rex, USN (OPNAV); Majors W. H. Best and T. H. Lewis, USAF, (Air Weather Service); Drs. H. Wexler and J. Smagorinsky (U.S. Weather Bureau).

[40] Report by the Ad Hoc Committee on Numerical Weather Prediction to the Joint Meteorological Committee on Joint Numerical Weather Prediction (NWP-10-53), 12 August 1953 (Wexler papers, B32, NWP). The technical consultants were from (1) IAS: John von Neumann, Roy Berggren, Julian Bigelow, Jule Charney, and Bruce Gilchrist; (2) IBM: C. C. Hurd, George W. Petrie, and John Sheldon; (3) University of Chicago: Sverre Petterssen and George W. Platzman;(4) Bureau of Standards, Charles B. Thompkins. Major P. D. Thompson, USAF was an "unaffiliated member."

[41] Ibid.

unit's organizational structure would be flexible enough to quickly adapt new research results to its operational program. The operational nature of the unit would produce results which would need to be closely and carefully examined. The weather services would then need to follow a course of action that would lead to the ultimate success of numerical weather prediction.

The Committee thus recommended that work on the joint unit move forward. The Weather Bureau would take administrative responsibility. All three weather services would provide funding. Its purpose fulfilled, the Ad Hoc Committee members proposed establishing a new Steering Committee. It would be responsible for the selection of a director for the new joint unit and help him implement the plan.

The mission of the Joint Numerical Weather Prediction Unit was:

> To produce on a current, routine, operational basis, prognostic charts of the 3-dimensional distribution of relevant meteorological elements by using numerical weather prediction (NWP) techniques, in order to improve the meteorological forecasting capabilities of the participating weather services.[42]

Operationally, the Unit would analyze and process data for NWP which could not be, or was not already being, undertaken by the WBAN Analysis Center. It would compute prognostic charts and create products from numerical output which would be most beneficial to field forecasters. Additionally, the Unit would verify the computer generated products – monitoring quality and making suggestions for further improvement. It would develop objective analysis methods and improve data handling techniques, extend models geographically, and adapt models for longer forecast periods. The Unit would liaise with other organizations, particularly those conducting NWP research, and determine the applicability of new research results to operational models. It would also conduct in-house training of personnel to maintain optimal personnel proficiency.

In the summer of 1953, the Ad Hoc Committee concluded that the IBM 701 was the best computing machine available. In fact, Committee members did not even discuss any other options and were perhaps at that stage unaware of any other options. What they did know was that by submitting a letter of intent before 30 September 1953, the computer could be available by 1 October 1954 – a full year later and three months after the JNWPU was to be established. To be co-located with WBAN, the facility needed at least 4500 square feet of floor space with a minimum of 1000 square feet set aside for the computer. After an initial outlay of $94,500, the Ad Hoc Committee estimated the budget for the first year of operations to be $415,000: $193,000 for personnel, $200,000 for the IBM computer, and $22,000 for miscellaneous expenses.[43]

Since the Unit was starting from nothing, the Ad Hoc Committee anticipated a three month "shakedown" period. During that time, the Unit would prepare and distribute one set of (unspecified) prognostic charts daily. Unit members would focus on the development and standardization of an operational routine. By placing the JNWPU next to the WBAN Analysis Center, the services hoped to eliminate duplication of effort – a long-time issue in the U.S.

[42] Enclosure: Plan for Joint Numerical Weather Prediction Unit, 12 August 1953 (Wexler papers, B32, NWP).

[43] Ibid.

government's provision of meteorological support to the nation. Concerns over so-called duplication of effort in the past had decimated military meteorological organizations at the end of periods of national emergency. The Weather Bureau, always low on the funding scale, would not have wanted its efficiency questioned yet again on this high-visibility, high-cost project with uncertain results. The WBAN could provide plotted maps to the Unit and would provide additional data as needed. Although the Unit might need to perform its own analyses to meet specific NWP requirements, i.e., any analyses needed to provide initial grid point values, WBAN analyses would be considered and used once the Unit had tested them and found them acceptable.[44]

In their pursuit of a routine schedule, Unit personnel would use a simple atmospheric model to develop the first prognoses. These would include the constant-pressure surface at several levels in addition to vertical velocity, average temperature, and perhaps large-scale rates of precipitation in a chart presentation. The charts would be available to WBAN, but the individual services could distribute them within their own systems. The services planned to transmit the numerically produced prognoses via their facsimile channels.[45]

Realizing that the Unit would need a strong verification program in order to effect improvement, the plan called for the evaluation of their prognoses without detailing exactly what methodology would be employed. The Unit would not actually develop models. Instead it would take models developed by R&D sites and adapt them for operational applications. Unit members would be able to extend the geographical area of the models; their goal was hemispheric coverage. The Unit would also be permitted and encouraged to extend the forecast period. Members would consider data processing improvements separately, with much of the emphasis on objective analysis techniques.[46]

Because of problems inherent to joint organizations, there had to be a forum for addressing inter-agency issues. These would be reported to the proposed Steering Committee on Numerical Weather Prediction (SCNWP) under the cognizance of the JMC. The SCNWP, composed of representatives from each service, would hear problems concerning service personnel, requirements being placed on the Unit, and technical matters external to the Unit. For example, each service would have mission requirements which demanded a particular product. If the Unit tried to meet too many of these service demands, it could find itself unable to complete its primary mission. The Steering Committee would act to sort out such conflicting requests. The director of the JNWPU would report to the Weather Bureau Chief on all administrative matters including finance, civilian personnel, and logistical support. Finally, a scientific advisory group composed of subject matter experts, e.g., meteorology, electrical engineering, mathematics, would visit periodically and provide technical advice to the Unit.[47]

Personnel would include the director, an assistant, and a mix of professional and technical workers. The director would have a broad background in both synoptic and theoretical meteorology in addition to having previous experience using mathematical and physical techniques in weather prediction. He would also be familiar with basic programming techniques. His assistant, who would help administer the unit, just needed to be "conversant" in the basic NWP concept, i.e., did not need to be a

[44] Ibid.
[45] Loc.cit., Appendix 9, para. 1b-d, 2.
[46] Loc. cit., Appendix, p. 9, para 3.
[47] Loc. cit., Appendix, Section III, para.1, p. 9.

meteorologist. But the person would need "tact" in order to facilitate the mission. The requirement for "tact" was probably a bit of an understatement. Trying to overcome the inherent inter-service rivalry between three competing weather services would not only take tact, but a huge amount of patience.

The remaining personnel would have meteorological and/or mathematics backgrounds. To get the Unit off to a good start, at least some of the incoming personnel would have to come from the ranks of those training with the Princeton or Stockholm groups, or working with the Thompson's Cambridge group. Otherwise, the experience level would be too low. Of great importance was the need for meteorologists conversant with both dynamics and synoptics – a combination that had not been encouraged in earlier years. The six meteorologists collectively, although not individually, would have strong dynamic meteorology and mathematics abilities, and be familiar with machine computations. However, they also needed to have extensive synoptic experience and knowledge of advanced prognostic techniques with "proven ability to carry out independent developmental research." These were definitely not entry level positions. By the very nature of the position description, the Unit needed to bring in people who had already been working on the developmental stages of NWP. The mathematician would need extensive experience in numerical analysis and the programming of complex physical programs. He would be joined by three programmer-coders who would also be strong mathematicians with programming experience. The meteorological analysts would perform synoptic map analysis. They were expected to be skilled synopticians, preferably with training and experience in dynamic meteorology, and have sufficient general knowledge of NWP to be useful team members. A number of lower-level technical positions rounded out the personnel: computer operators, meteorological aids to plot data, plotters to check and plot data, and a secretary to support the Unit's administrative needs.[48]

Securing the computing machine and providing a properly engineered space for it would be two key challenges facing the new Steering Committee. This Committee would be faced with three basic options for obtaining the required computing machine: build it, purchase it off-the-shelf, or lease it. Ordering a custom-built computer was a very expensive option that would limit the Unit's flexibility given the rapid pace of computer development. Buying a commercial computer "off-the-shelf" would also limit the Unit's flexibility to upgrade as newer, more advanced computers came on-line. Thus, leasing the machine was the best approach. The Unit could then make equipment upgrades without the large investment of funds. Perhaps just as important, the providing company would handle the maintenance. Thus, the Unit would save on manpower costs and avoid the problems of finding and hiring qualified people (of which there were probably few in 1953) to maintain the computer and associated peripheral equipment. The Committee thought the IBM 701, known within the company as the "Defense Calculator," was the best choice. Designed to meet the demands of the Defense Department and the aerospace industry – which, indeed, used almost all of the nineteen extant machines – the design logic and high speed memory were virtually the same as the IAS computer.[49] With an extremely flexible input/output scheme and a promise from IBM to cooperate on automatic data processing development, the 701 was clearly superior to other options.

[48]Loc. cit., Appendix, Section III, p. 12-13.
[49] Ceruzzi (1998), 34.

The IBM 701 came with its own set of siting requirements which the Unit had to address before accepting delivery. Sufficient heating, lighting and power systems were available in the spaces adjacent to the WBAN. However, the required 30 tons of air conditioning were not. The room needed to be retrofitted with a raised floor to allow for cabling and air conditioning ducts. In addition, the IBM engineers would need an engineering room close by for themselves and their equipment.[50]

Wexler, the Weather Bureau's representative on the Ad Hoc Committee, was determined that nothing should get in the way of this project's forward movement at this late stage. Advising his boss, Reichelderfer, of the financial and personnel burden the Weather Bureau could anticipate sharing, Wexler argued that NWP was "no longer the 'meteorological oddity' of L. F. Richardson's pioneering efforts of 1922." Richardson's ideas for forecasting the weather by numerical means were viewed with some interest in 1922, but quickly abandoned as being completely impractical in a world where all computations were done by hand. Wexler assured Reichelderfer that the current approach to numerical weather prediction, as developed by the Princeton group, was sound. As proof of its "soundness," Wexler pointed to the independent tests being performed in a number of countries and mentioned the operational approaches being undertaken in Sweden (by Rossby's group), England (by the British Meteorological Office), and in the western zone of Germany (by Deutscher Wetterdienst). The foresighted Wexler envisioned NWP as the future nucleus of Weather Bureau's forecasting efforts. He expected forecasts to become available at lower cost as computers became faster and more efficient. Wexler also argued that the Weather Bureau "should not become the 'poor silent relative'" and should make sure everyone knew that it had carried its fair share of the financial burden.[51]

Reichelderfer not only needed allies within the military services to bring the JNWPU to operational reality – he needed allies within the Weather Bureau's umbrella organization: the Department of Commerce. Without support for the Weather Bureau's budget, including any last minute increases to cover the costs of the new Joint Unit, the Bureau would be unable to fulfill its obligations to the other weather services. Writing to the Honorable Robert B. Murray, Jr., Under Secretary for Transportation, Reichelderfer reiterated the discussions of previous meetings wherein he had set forth the future of forecasting by electronic computers. Acknowledging that the forecasting technique of the moment was the forecaster's personal judgment based on the data as he saw them, Reichelderfer maintained that this new objective technique would eventually, if slowly, lead to more accurate forecasts in the support of aviation, agriculture, and other areas of economic interest. In other words, NWP would ultimately be of benefit to the commercial sector through increased safety of flight, reduced losses of agricultural products both in the ground and en route to market, and improved timing of business decisions dependent upon the weather. Yes, the equipment would be expensive, but future personnel reductions (due to the work being done by the computers) would provide the savings to pay for the new hardware. He reassured the Under Secretary that the

[50] Enclosure: Plan for Joint Numerical Weather Prediction Unit, Appendix, Section IV, Para 1 and 3, 12 August 1953 (Wexler papers, B32, NWP).

[51] Wexler to Reichelderfer, 12 August 1953 (final), 31 July 1953 (initial) (Wexler papers, B32, NWP). Between the initial and final report, the Weather Bureau's share of the budget decreased from $144,000 to $139,000. The number of professional meteorologist positions, to be shared among all three services, dropped from sixteen to thirteen.

Bureau would be able to remain within their fiscal year 1954 budget appropriation. A note at the bottom to "Interested Project Leaders" made clear that the Weather Bureau intended to fully support numerical weather prediction.[52] The unspoken message was, "and I expect that you will support it also."

Another major issue the establishment of the Joint Unit raised was a familiar one in 20th century technology: whether increased mechanization would lead to a reduction in the number of workers. It is not surprising that Reichelderfer made the case for automation as a way to reduce the number of people required to produce forecasts. Due to considerable fiscal belt-tightening occurring in the Eisenhower administration, less money, not more, would be available in the future. Thus, governmental agencies needed to become more "efficient." Personnel reductions not only saved money in the near-term, they saved money in the long-term by eliminating pension costs.[53] However, this argument in support of possible personnel reductions was in direct opposition to the statement made by Smagorinsky during his presentation on the Radio WGY Science Forum. At that time, he had argued that there would be no reduction in the number of meteorologists at the Weather Bureau because they would still be needed to put out the local forecasts. Numerical weather prediction would just provide them with more reliable information than was currently available from subjectively produced charts.[54] Perhaps Reichelderfer thought that they would need less manpower for the routine work done by technicians in plotting and preparing the raw data for analysis. However, as in many cases where automation was considered the savior of personnel costs, the addition of computers would lead to reassignments, not personnel reductions.

By the end of August 1953, the JMC had still not decided whether the JNWPU would be an independent entity or subsumed within the WBAN Analysis Center. The JMC's Air Force representative had expressed a preference for integrating the Unit within the Analysis Center.[55] However, the Navy was not yet willing to make a binding commitment, and wanted more time to discuss it in-house. The Weather Bureau's representative, Smagorinsky, thought the decision hinged on a possible change to the external structure of supervision for the Unit, i.e., how it would relate to the steering and advisory committees. Or on a third possibility: "horse-trading." The military services were apprehensive about the Weather Bureau funding its full share. Their concern surprised Smagorinsky, who did not view funding as a problem. He was more worried about space issues. After all, the Weather Bureau had to move the WBAN into a new building and determine how the Joint Unit would be co-located with it. A delay in the WBAN move would adversely impact the Unit. Smagorinsky also reported some unanticipated equipment problems. The decision to use the IBM 701 had been called into question. Securing the computer might not be as easy as just signing a letter of intent to lease.[56]

The Eisenhower Administration's emphasis on fiscal conservatism soon threatened to derail the computer acquisition plans. Reichelderfer received a query from Assistant Secretary of Commerce James C. Worthy wanting to know why the JNWPU

[52] Reichelderfer to R. B. Murray, Jr., 14 August 1953 (Wexler papers, B32, NWP).
[53] Reichelderfer to Project Leaders, 28 August 1953 (Wexler papers, B32, NWP).
[54] Joseph Smagorinsky, "Numerical Weather Prediction," address on the WGY Science Forum, 20 May 1953 (Wexler papers, B32, NWP).
[55] Reichelderfer to Project Leaders, 28 August 28 1953 (Wexler papers, B32, NWP).
[56] J. Smagorinsky to H. Wexler, 19 August 1953 (Wexler papers, B32, NWP).

could not use the Bureau of Census Machine Tabulation Facilities instead of a dedicated computer. If the Weather Bureau did plan to use the Census facilities, Worthy wanted a detailed description of the "nature and scope" of the proposed usage. Reichelderfer needed input from his division heads in order to answer these questions.[57] Attempts to save money by sharing computing equipment would be problematic if the Unit were expected to do its runs around other agencies' needs.

Wexler took on the response to Worthy. He forcefully argued that the Census facilities were inappropriate either for the Unit or for the extended forecast division. The Unit needed a machine that matched the capacity and speed of the IBM 701. The Census machine did not meet these basic requirements. Additionally, the Unit would need to use the computer 70 hours per week on a very firm schedule. As the operations become more successful and their numbers increased, Wexler anticipated that the run-time might double after the first year. Even in the early shake-down stages, Unit personnel could not be kept waiting for the Census Bureau staff to finish running their tabulations. The whole idea of behind the creation of an operational unit was to meet operational demands. Weather forecasts could not wait for the kind of non-time-critical statistical calculations of importance to the Census Bureau. Therefore, a shared machine was absolutely out of the question. Wexler's other concern was for the extended forecast section's computer requirements. Due to short lead times, the extended forecast group had to be co-located with its computer. Often the data were ready for processing just a short time before the run. If computer sharing with the Census Bureau became a reality, there would only be two options: move the extended forecasting section to the Census Bureau, or haul the data on punched cards to the Census Bureau. Either option was untenable. It made no sense to move extended forecast meteorologists away from the rest of the Weather Bureau professional staff. Likewise, driving numerous large decks of cards around the greater Washington, D.C. area during the rush hour, nasty winter weather, or other traffic disasters, would adversely impact the creation of a timely product. Worse yet, what if someone dropped the decks of cards? Huge amounts of time would be wasted. The Weather Bureau required a dedicated computer.[58]

Wexler was very sensitive to Reichelderfer's fiscal worries. Therefore, Wexler presented the argument in favor of leasing as being the most fiscally responsible choice. The computing power required to do meteorological work, both to run realistic atmospheric models and to automatically process data, was so great that existing computers were only marginally able to meet the challenge. The Meteorology Project had already come to that conclusion while running their simple models on von Neumann's machine. Continuous design improvements on computers meant that each new upgrade ran faster and had more memory than any previous models. That being the case, it did not make good economic sense to purchase a machine. It would be outmoded very quickly and if they purchased it, the Weather Bureau would be responsible for the maintenance. In Wexler's view, when the "situation stabilizes," i.e., when computer design slowed so that new, faster models were not continuously being made available, then it would make more sense to purchase one.[59] Reichelderfer concurred in Wexler's assessment.

[57] F. W. Reichelderfer to Division Heads, 21 August 1953 (Wexler papers, B32, NWP).

[58] Wexler to Reichelderfer, 27 August 1953 (Wexler papers, B6, F1953).

[59] Wexler to Reichelderfer, 3 September 1953 (Wexler papers, B6, F1953).

However, Reichelderfer argued that government officials, including Congressional authorities, Bureau of the Budget personnel, and high ranking members of the Executive Branch were convinced that too much money was being spent on "machine tabulation equipment." Reichelderfer, and other agency heads, were under pressure to share this equipment whenever possible. Therein lay the suggestions by Worthy that the Weather Bureau share the computers already in place at the Bureau of Standards and the Bureau of the Census. Reichelderfer did not want to appear uncooperative with efforts to economize on computing equipment by insisting that his organization required a dedicated computer. Therefore, he proposed that the Weather Bureau "not give the appearance of obstructing the plan in the beginning by starting off with reasons why we cannot do it." He seemed to think that the reasons would "speak for themselves" once the requirements were reviewed by the Census Bureau and the Department of Commerce.[60] Counting on other agencies to see the wisdom of his thinking was, however, somewhat risky. They already owned the machines – Reichelderfer would be the one coming hat-in-hand. If Census and Standards had thought the Weather Bureau would take over their machines, then he could have counted on their support as well for a dedicated weather computer.

Even as the United States' JNWPU was finalizing its plans to take numerical weather prediction operational, the Swedish group was making rapid progress as well. Phillips wrote from Stockholm that their computer, BESK, was almost finished. Rossby's team members were just waiting for the completion of the input mechanism so they could start making calculations. Although the new magnetic drum would not be ready for a while, Rossby's group intended to start without it. The BESK had the option of three different electrostatic memory sizes: 256, 512, or 1024 words (40 bit). The Stockholm group was planning on using the 512 word setup with the barotropic code using a simple Liebmann, Jacobian scheme. The code would be in three parts: Liebmann, Jacobian and transformation. Thus, each part of the code was no more than 100 words, allowing for a 20x20 grid. Rossby's on-site mathematician had wanted to use a more complicated formula, but it was less stable than the simple centered-difference formulae. Phillips thought the same was true of the formulae Rossby had been using, but had been unable to convince his colleagues that might be the case.

Elsewhere in Europe, Hinkelmann in West Germany had signed a contract with the U.S. Air Force for numerical prediction "including the building of a machine." This was an outgrowth of Thompson's European visit. The Air Weather Service wanted numerical weather prediction support for its assets in Europe, but was not able to provide them from the United States – computers were neither big enough nor fast enough to process all the data. Therefore, the Air Force's solution was to establish numerical weather prediction centers, not unlike the JNWPU, wherever needed. Two members of Hinkelmann's team were in Stockholm, and Hinkelmann was scheduled to join the Stockholm group in January 1954.[61] So despite the Air Force's desire to participate in the Joint Unit, the Air Weather Service was working to expand its NWP assets by setting up a computer unit in Europe in addition to maintaining Thompson's group in Cambridge.

The JMC ultimately approved most of the plans for the JNWPU. However, they shelved the idea of leasing the IBM 701

[60] Reichelderfer to Wexler, 8 September 1953 (Wexler papers, B6, F1953).

[61] Phillips to Charney, undated, ca. Fall 1953 (Charney papers, B14, F449).

without a competitive bid. Dr. J. J. Eachus, a JNWPU project consultant and National Security Agency staffer, had recommended that the new Steering Committee explore the possibility of using Remington-Rand's ERA 1103 instead of the IBM 701. The JMC also decided to authorize the JNWPU to call in consultants as needed instead of creating a permanent scientific advisory group. With the JMC's acceptance of the plan proposed by the Ad Hoc Committee on Numerical Weather Prediction, the latter's work was done. It was dissolved and a new Ad Hoc Group for the Establishment of a Joint Numerical Weather Prediction Unit (en lieu of a steering committee) was created with Rex, once again, as chairman. He was joined by Air Force Major T. H. Lewis representing the Air Weather Service, and Wexler representing the Weather Bureau. Since they had also composed the first *ad hoc* committee, any change was in name only.

The Group's first task was to select a director for the JNWPU.[62] The members unanimously recommended Air Weather Service meteorologist Dr. George P. Cressman (b. 1919).[63] Cressman, who had earned his Ph.D. at Chicago during Rossby's tenure, was a "well recognized" authority on synoptic meteorology, and had had experience with all three of the weather services composing the JNWPU. The Group approached Cressman informally and he agreed to fill the position if it were formally offered.[64] With the JNWPU expected to be operational on 1 July 1954, the Ad Hoc Group now had less than a year to finalize computer, funding, space, and personnel arrangements.

The computer question would prove to be a difficult one for the Group, particularly given this multi-agency scenario. Two of the three weather services were subsets of the Department of Defense; one fell under the Department of Commerce. Not only did the agencies have to agree on the computer, they had to convince their cabinet-level superiors that it was the right thing to do. This was apparently more of a problem for the Weather Bureau than for the military services which were, at the time, not as budget constrained for computing equipment. Since the new Joint Unit was a government entity, a competitive bid was required. There were very few computer manufacturers. There were even fewer computers that could handle the atmospheric problem. How would the Group make that kind of decision? Before asking the firms for bids, the Group would need to be very clear about what the computing requirements were – not only for the models, but for data handling. These areas were still works in progress. There was no guarantee that, in the year it took to build the chosen computer, they would not have a "better" model no longer able to run on it comfortably. While dealing with external inquiries about why they needed a dedicated computer, the Ad Hoc Group asked consultants to help them make a decision that would shape the early success or failure of the JNWPU.

Thus started the quest for a competitive bid in an era when there were few potential bidders. To enable the Group to make an intelligent computer choice, Smagorinsky invited the only two firms with competitive machines – IBM and Remington-Rand – to perform preliminary tests to demonstrate the capabilities of their machines. The Group members invited von Neumann, Charney, Petterssen, Eachus, Bigelow, and Platzman to serve as an

[62] Joint Meteorological Committee (JMC-78-53) to Chairman, Ad Hoc Group for Establishment of a Joint Numerical Weather Prediction Unit, 17 September 1953 (Wexler papers, B6, F1953).

[63] Cressman would go on to become the Director of the National Weather Service.

[64] D. F. Rex, Chairman, Ad Hoc Group to Secretary, Joint Meteorological Committee (JNWP-2-53), 22 September 1953 (Wexler papers, B6, F1953).

informal technical advisory committee and to help them analyze the results.[65]

Group members, Cressman, Smagorinsky, and company representatives met in early October 1953. The Group asked both companies to run the three-dimensional quasi-linear model. IBM had a 701 ready to run such a model, but would not encode it for the 701 without compensation. The IBM representatives said they had a 701 available for the test run in the Washington, D.C. area that was already operating two eight-hour shifts per day, five days a week at 75% efficiency. IBM could still deliver a 701 to the JNWPU within a year of receiving a letter of intent. Remington-Rand offered to do the model coding for free, but did not have an ERA 1103 available to run it. (Exactly how they expected to run a competitive test without a computer is a mystery. According to Paul Ceruzzi, Remington-Rand, which had acquired both UNIVAC and Engineering Research Associates (ERA), "did not fully understand what it had bought."[66] Consequently, it did not know how to market its computers.) The Remington-Rand representatives did not know when they could deliver an operational computer or how they would handle maintenance issues, but agreed to get back with those answers.

Smagorinsky and Goldstine were designated as "fact finders" – they would determine the suitability of the computers for the meteorological task and report back to the technical advisors.[67] Since Goldstine was already under contract to ONR, Rex asked ONR to make his services available.[68] Within a couple of weeks, Remington-Rand had found machine time and IBM had identified a program that could be run on its 701. The competitive process continued.[69] It appeared that the test runs could start in December and should be completed by the middle of January 1954. [70] The technical advisors would meet at IAS, after the runs were done, to make a decision which was hoped to occur before 10 February.[71]

Goldstine and Smagorinsky filed their tentative report at the end of January. Their report was based on the companies' advertising material, personal inquiries, and the test run of the model on each machine. To give the technical advisors enough material with which to make a decision, they outlined modeling, data handling, and other issues which would have an impact on run times.

The computer selection would depend heavily on the kinds of models the JNWPU would run within its first year. There was no point in selecting a machine that could not handle the initial modeling and data handling requirements. It made no sense to choose a machine that could handle the initial models, but would not be able to run models incorporating larger geographical areas, additional variables, or increased forecast periods. Smagorinsky and

[65] JCS/JMC Ad Hoc Group for Establishment of a Joint Numerical Weather Prediction Unit (JNWP-1-53) Minutes of the first meeting held 22 September 1953 (Wexler papers, B6, F1953).

[66] Ceruzzi, *History of Modern Computing*, 45.

[67] JCS/JMC Ad Hoc Group for Establishment of a Joint Numerical Weather Prediction Unit (JNWP-11-53) Minutes of the second meeting held 6 October 1953 (Wexler papers, B6, F1953).

[68] Chairman, Ad Hoc Group for the Establishment of a JNWPU to Chief of Naval Research (JNWP-9-53), 8 October 1953 (Wexler papers, B6, F1953).

[69] JCS/JMC Ad Hoc Group for Establishment of a Joint Numerical Weather Prediction Unit (JNWP-11-53) Minutes of the third meeting held 12 October 1953 (Wexler papers, B6, F1953).

[70] JCS/JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 4th meeting held 28 October 1953 (JNWP-18-53) (Wexler papers, B6, F1953).

[71] JCS/ JCS/JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 6th Meeting held on 7 December 1953 (JNWP-27-53); JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 7th Meeting held on 7 January 1954 (JNWP-4-54) (Wexler papers, B32, NWP).

Goldstine anticipated that the first year's models would include large-scale motions, assume an adiabatic and frictionless atmosphere, and could consider an irregular lower boundary. In mathematical terms, the model represented an initial value problem wherein the geometric boundary conditions were specified at all times. It would have three internal vertical grid points, be quasi-linearized, and have a level lower boundary, i.e., it would not consider topography. The computer would have to solve two-dimensional elliptic Helmholtz equations in successive times. Any inhomogeneous terms would require Jacobian operations to be applied to functions of earlier solutions of Helmholtz equations. The more general model would have 5 to 7 vertical grid points, an irregular lower boundary, and would require the solution of the three-dimensional Poisson equation. The inhomogeneous terms in the Poisson equations would require additional two-dimensional Jacobians. With a horizontal lattice of at least 20x20, Smagorinsky and Goldstine estimated that the run time would be at least five times greater than that required by the quasi-linear, three-level model.

Manual data handling was far too slow and inaccurate for later calculations. Automatic data processing was a non-negotiable requirement. This would require the inversion of about 1000 10x10 symmetric matrices and would require significant amounts of machine time.

Increasing geographic coverage, including moisture distributions for precipitation forecasts and three-dimensional trajectories for condensation computations, would also increase run times. Given these possibilities, Smagorinsky and Goldstine thought it likely that within a few years the time requirements on the computer would be an order of magnitude greater than for the test problem. Since operational predictions would require a faster run time, the JNWPU's ability to function effectively would depend on the availability of newer, faster machines.[72]

On a chilly January day in Princeton, the technical advisors, along with the Ad Hoc Group and Goldstine, Gilchrist, Glen Lewis (all from IAS) and Lieutenant Commander C. A. Palmer (ONR), met at IAS to choose the computer.[73] Von Neumann chaired the meeting. Rex provided background information. He stressed the importance of leasing the computer for at least a year – an earlier change would disrupt the operation. Then Smagorinsky and Goldstine presented their report. Discussion followed. The computers handled the test problem with virtually the same run time. Remington-Rand's ERA 1103 showed faster internal calculations, but the IBM 701 had faster output so there was no significant end-result difference. As model complexity increased, both machines would reach the limit of their processing capabilities at about the same time. Because of large data input and output requirements, it was important to have rapid printer output. The 1103 did not have an integrated high-speed line printer. Meeting attendees concluded that the 701 would likely have a better maintenance program because IBM, with more of the machines on-line, had had significantly more experience with maintaining the machines. Since both bids were essentially the same, the more reliable

[72] Tentative Report to the Ad Hoc Group for Establishment of a Joint Numerical Weather Prediction Unit, The ERA 1103 and the IBM 701, 26 January 1954 (Charney papers, B16, F 522). Although it is not signed, this was the report produced by Smagorinsky and Goldstine.

[73] The list of technical advisors had grown and at this point included von Neumann, Charney and Bigelow (all from IAS), Tompkins (Bureau of Standards), Eachus (National Security Agency), mathematician Mina Rees (Hunter College), and C.V. L. Smith (ONR).

IBM machine would be the better choice.[74] Therefore, with the one year lead time rapidly shrinking, the Group recommended the selection of the IBM 701 "Defense Calculator."[75]

About the time Reichelderfer had convinced Worthy that the Weather Bureau absolutely had to have a dedicated computer, another Commerce Department bureaucrat – Under Secretary for Transportation Murray – weighed in with his off-the-wall question: Why not just use the best parts of the IBM and Remington-Rand computers to form a computer better than either of them were individually? Once again, Wexler was stuck researching the question. He turned to Eachus to find out the feasibility and cost of such an undertaking. At least Reichelderfer could answer Murray's other question: Why not just purchase the machine? Reichelderfer was fully aware that either machine would be obsolete too soon. However, they could not wait two to three years for the next generation of computers to arrive before moving ahead with numerical weather prediction.[76]

Having made its decision, the Group notified IBM of the 701's selection. Smagorinsky and Cressman were scheduled to attend a training seminar at IBM. While there, they would give the IBM staff more information on the history and future of NWP. The Weather Bureau's financial maven – Robert N. Culnan – negotiated the final details and sent the letter of intent.[77] Only four months remained until the JNWPU would open for business.

At the end of May, just when things looked settled for the computer, IBM announced their new, improved computer – the 704. If desired, IBM would substitute the 704 for the 701 ordered by the Weather Bureau. The Ad Hoc Group members tossed the idea around and unanimously agreed to stay with the 701. They had two reasons: a change to the 704 would delay delivery by several more months (and they were already behind schedule due to the late selection of the 701), and the 704, besides being more expensive, did not have a proven operational track record. That the 704 was supposedly faster and more flexible than the 701 did not outweigh its negative points.[78] The official delivery date for the 701 was now 1 March 1955. JNWPU members had at most ten months to test and refine their initial model.[79]

As the opening day drew closer, personnel issues were being settled by inter-agency horse-trading of people and money. Since the Unit would have both military and civilian personnel under civilian leadership, the potential for inter-agency conflict was

[74] Minutes of the First Meeting of the Technical Advisory Group, Ad Hoc Group for Establishment of a Joint Numerical Weather Prediction Unit (JNWP-6-54) (Wexler papers, B6, F1953).

[75] Draft JCS/JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 8th Meeting held on 28 January 1954 (JNWP-7-54) (Wexler papers, B32, NWP). Although this information did not appear in the final version of the minutes, the draft minutes listed all the equipment: 1 electrostatic frame, 4 magnetic tape frames, 1 magnetic drum frame, 1 card reader, 1 card punch, 1 high-speed line printer, and 1 power and control unit.

[76] Reichelderfer to Project Leader (Smagorinsky), 19 February 1954 (Wexler papers, B6, F1954).

[77] JCS/JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 10th Meeting held on 26 February 1954 (JNWP-12-54) (Wexler papers, B32, NWP); G. W. Petrie, IBM to George Kressman (sic) and Joseph Smagorinsky, 4 March 1954 (Wexler papers, B32, NWP); JCS/JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 11th Meeting held on 11 March 1954 (JNWP-16-54) (Wexler papers, B32, NWP).

[78] JCS/JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 14th Meeting held on 28 May 1954 (JNWP-19-54) (Wexler papers, B32, NWP).

[79] Final Report of the Ad Hoc Group for Establishment of a Joint Numerical Weather Prediction Unit, 30 June 1954 (Enclosure (1) to the Minutes of the 15th meeting held 1 July 1954) (Wexler papers, B32, NWP).

almost a given. However, by working closely together from the beginning, the Ad Hoc Group was trying to minimize those problems and get the JNWPU off to a good start with capable, enthusiastic personnel. Since some of the services could provide more people than others, the Group decided to trade people for cash. Weather services providing fewer people than previously agreed would make up the difference by transferring more funds to the JNWPU. The Weather Bureau was able to free up positions to cover their obligation, but the Navy could only provide two officers: a meteorologist and a programmer-coder. This was a significantly smaller personnel contribution than the other services. Cressman still had not found a suitable programmer-mathematician, so the Group sought recommendations for possible candidates from authorities in technical fields.[80] As applications came in, they were forwarded to Cressman. He, in turn, kept the Group advised on personnel issues.[81] The JNWPU had two strikes against it from the beginning: it was an entirely untested organization creating untested meteorological products, and the personnel it needed were, likewise, entering an entirely new field which they were learning on the job. Therefore, it is truly amazing that the proposed internal structure for the JNWPU remained in place as hiring continued. Staff recruitment went smoothly, but Cressman decided not to fill sub-professional positions until a permanent home had been found for the JNWPU.[82]

By the time the Ad Hoc Group made its final report and the JNWPU became a reality in July 1954, all but three professional positions had been filled. Of the professional core, seven each were from the Weather Bureau and Air Force, while three were from the Navy. The Unit was still short one meteorologist and two operators, but interviews were in progress. The Air Force provided three sub-professional staff members and the Weather Bureau one. The remaining ten positions would be assigned out of Weather Bureau assets as needed.[83]

Just as the JNWPU was officially coming to life, the British Meteorological Office (BMO) arranged to exchange a meteorologist with the Weather Bureau. The BMO wanted their meteorologist to work with the JNWPU in order to come up-to-speed on developments in NWP. The BMO had its own proposed operational NWP group and wanted their man to get some hands-on training and experience. Thus the Unit would get one more person – and as Reichelderfer noted, it would be somebody very good.[84]

Since the Weather Bureau had administrative authority over the JNWPU, Wexler coordinated the appointment of a financial representative from within the Bureau.[85] Culnan thus became the financial coordinator and established contacts with the Air Force and Navy representatives. However, there would be no fund transfers

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[80] Ibid.

[81] JCS/JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 5th Meeting held on 20 November 1953 (JNWP-19-53) (Wexler papers, B6, F1953).

[82] JCS/JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 6th Meeting held on 7 December 1953 (JNWP-27-53) (Wexler papers, B32, NWP). Final version JCS/JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 8th Meeting held on 28 January 1954 (JNWP-7-54) (Wexler papers, B32, NWP).

[83] Final Report of the Ad Hoc Group for Establishment of a Joint Numerical Weather Prediction Unit dated 30 June 1954 (Enclosure (1) to the Minutes of the 15th meeting held 1 July 1954) (Wexler Papers, B 32, NWP).

[84] Reichelderfer (writing from Geneva) to Scientific Services Division , 28 August 1954 (Wexler papers, B6, F1954).

[85] JCS/JMC Ad Hoc Group for Establishment of a Joint Numerical Weather Prediction Unit (JNWP-1-53) Minutes of the 1st meeting held 22 September 1953 (Wexler papers, B6, F1953).

until space modification expenses had been ascertained, and that depended on the exact location of the JNWPU. The Group anticipated a decision by early 1954.[86]

However, by January 1954 there was still no decision. That was creating problems. Without a firm location, the Weather Bureau could not develop a final budget. Despite that, the Group decided that each service should transfer funds – about $31,500 – to cover one-third of the proposed start-up budget to the Weather Bureau, and that Cressman should be authorized to expend those funds.[87] The JMC approved and directed both actions to take place.[88]

On 17 February 1954, the JMC formally designated the Weather Bureau responsible for administering the JNWPU. Reichelderfer wrote to Wexler, "This is a major responsibility. Be sure that we set up arrangements to do the job well." Since Wexler had been intimately involved with the early planning of the Unit, this statement seems superfluous. Reichelderfer was clearly concerned that the Weather Bureau might receive the brunt of the criticism if the Unit did not prove to be successful.[89]

By mid-summer, space had been allocated in Federal Office Building No. 4 in Suitland, Maryland – not next to the WBAN Analysis Center (also in Suitland) as had been previously planned. However, this new location was adjacent to that which would be occupied by the National Weather Analysis Center – the WBAN's successor. In the meantime, the JNWPU would occupy space made available by the Weather Bureau. In financial matters, of the $94,500 start-up funds, approximately $82,000 would be used to modify spaces, power and electrical installations, and engineering services. The remaining money would be used for miscellaneous equipment and furniture. For fiscal year 1955, the estimated expenditure was $311,000, or $103,700 per service. Since the Navy was providing fewer people, its cash contribution was almost twice as high as that from the other two services. By providing more than one-third of the personnel, the Air Force actually reduced its expected cash contribution.[90]

Unfortunately, an unexpected complication appeared. The Air Force member, Major Lewis, reported that another JMC *ad hoc* group had recommended that the WBAN Analysis Center adopt a 1:20,000,000 map for future use. However, such a scale was not useful for NWP work. In fact, IAS, the Weather Bureau and the Air Force had shown that if the map scale were smaller than 1:12,500,000 it could not be used in numerical weather prediction. To make matters worse, the JNWPU budget proposal had counted on the availability of the 1:12,500,000 scale maps. If the map scale changed, the Unit would need to make other arrangements to obtain the correctly scaled maps.[91] The issue came up again two

[86] JCS/JMC Ad Hoc Group for Establishment of a JNWPU, Minutes of the 4th Meeting held 28 October 1953 (JNWP-18-53) (Wexler papers, B6, F1953).
[87] Draft JCS/JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 8th Meeting held on 28 January 1954 (JNWP-7-54) (Wexler papers, B32, NWP).
[88] JCS/JMC to the Ad Hoc Group (JMC-26-54), 23 February 1954 (Wexler papers, B6, F1954).
[89] Reichelderfer to Wexler, 24 February 1954 (Wexler papers, B6, F1954).
[90] Final Report of the Ad Hoc Group for Establishment of a Joint Numerical Weather Prediction Unit, 30 June 1954 (Enclosure (1) to the Minutes of the 15th meeting held 1 July 1954) (Wexler papers, B32, NWP). The estimated personnel expenses obtained by using mid-grade Civil Service salaries came to $191,525. The IBM 701 (and peripherals) lease would be approximately $97,000 for the four months from March through June 1955. Additional cost account items included travel, phones, utilities, printing, and office supplies for a total of approximately $22,000.
[91] JCS/JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 5th Meeting held on 20 November 1953 (JNWP-19-53) (Wexler papers, B6, F1953). The *ad hoc* group in question was the JMC

months later. JMC members told the Ad Hoc Group that the WBAN would be able to provide the maps to the required scale *if* the WBAN Center had "suitable transforming or enlargement facilities."[92] However, the JMC members gave no indication that such facilities were actually available. Even if they were, the re-scaling of maps would delay data flowing to the JNWPU.

While computer, space, funding, and personnel issues were all being addressed by the service representatives in Washington, D.C., the Princeton group continued to work on the models. The Meteorology Project members had two basic missions: to clean up the models that would be run operationally, and to gradually extend the forecast lengths for those and other models for future use. The personnel situation had improved dramatically with the help of an infusion of foreign meteorological blood. Joining Charney were Scandinavians Berggren, Bolin and Fjörtoft, and Britons Eady and Gilchrist. Visiting "consultants" – who visited IAS for a few days each – were all from outside the United States. Four representatives from the weather services were in Princeton for training before transferring to the JNWPU. Phillips was in Stockholm with Rossby. And so the international nature of the Meteorology Project continued.[93]

The Meteorology Group had gradually shifted its attention to longer range forecasts since the quasi-geostrophic models and their ability to predict short-range events had become rather routine. However, there was still some cleaning up to do before the model went operational, so team members had not abandoned short-term forecast work entirely.

Team members, busy working on case studies and investigations of additional atmospheric influences on the general circulation, continued to make important advances during the period of preparation for operational numerical weather prediction. They made forecasts with the three-level model for two more cyclogenetical periods in the eastern United States. In both cases, the model successfully predicted cyclogenesis. Those successes indicated that large-scale middle latitude storms were predictable, quasi-geostrophic and quasi-isentropic – good news for operational applications.

Project members also investigated the effects of horizontal-vertical vorticity conversion, vertical advection of vorticity, influence of mountain ranges, and vertical propagation of energy – none of which had been included in simpler versions of the two- and three-level models. To handle these effects, they integrated the general quasi-geostrophic equations using potential temperature as a vertical coordinate. During the check-out phase of the coding, team members determined that they needed to make fundamental changes in the treatment of the lower boundary potential vorticities before making computations. Since they had had limited experience in the integration of multi-level model equations in the vertical coordinate, team members decided to make additional investigations using pressure as the vertical coordinate before modifying the equations further. To that end, they programmed two five-level models using pressure in the vertical (one model was run on the IAS computer and the other on an IBM computer in New York City). The IAS model had to integrate a highly non-linear

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Ad Hoc Group for Development of Plans for Consolidation of Analysis Functions in the Washington Area.

[92] JCS/JMC (JMC-4-54) to Ad Hoc Group for Establishment of a Joint Numerical Weather Prediction Unit, 11 January 1954 (Wexler papers, B6, F1954) .

[93] The Institute for Advanced Study, Meteorology Project, Progress Report July 1, 1953 to March 31, 1954, Contract No. N-6-ori-139 (1), NR 082-008 (Charney papers, B9, F305).

partial differential equation, and the potential vorticities carried the history of motion. In the IBM model, the contour heights of the isobaric surfaces carried the history of the motion. Neither model included topography, and the IAS model did not include the vertical advection of potential vorticity. Both used 1000, 800, 600, 400, and 200 mb pressure levels. By March 1954, the Princeton team members had run both models out to 5 hours and were planning to extend them to 24 hours. Cyclogenesis began at the ground and worked its way up into the atmosphere in both models. In preparation for longer period predictions, the group members wanted to explore how far into the future they could successfully extend the predictive period if they took into account energy sources and sinks, and the non-homogeneity of the earth's surface with respect to heat, water vapor, and momentum transfer. The models had to describe the essential processes governing the life-cycle of a single large-scale atmospheric system and account for the "general circulation" of the atmosphere. From previous work, it appeared that it was necessary to have at least three levels in order to predict cyclogenesis, i.e., the development of the large-scale system. However, team members worried that they had not conclusively ruled out the efficacy of the two-level model. Team members had gotten good results from some two-level models, and the results from the three-level models appeared to depend on the chosen levels. In the latter case, the model using 900, 700 and 400 mb data gave a better result than the model that used 850, 500 and 200 mb data. Therefore, they planned additional investigations.

Truncation and round-off errors had become a problem when the forecast was extended out for long periods. To determine the source of the error, the team used a barotropic model with idealized initial data and carried the calculations out for up to 14 days. An analysis of the computations showed that round-off error was not a problem; truncation error was. Team members then considered a variety of smoothing techniques to reduce this error.

Because the geostrophic model was unable to adequately explain the birth of fronts and jets, the team members continued their investigations into the properties of the general equations of motion. Aided by von Neumann's fix of a boundary condition problem, they started by integrating the equations for a one-layer atmosphere with a free surface. Programmed and coded, this method was awaiting check-out. Team members also devised a method of minimizing the effects of gravitational wave energy. On work related to existing models, Charney created a similarity theory which reduced the speed of long-gravity waves in both baroclinic and barotropic atmospheres, thus reducing computation time.

Work on an objective analysis method continued by taking wind and height values on an isobaric surface and interpolating height values at the grid points using a least squares method. The code allowed team members to instruct the computer to draw contours. By interpolating forecast data into data sparse regions, i.e., large unpopulated areas of the United States or oceanic areas, the team could ensure continuity between time periods.

Charney, Eady, and Fjörtoft also pursued a variety of theoretical investigations. Charney completed a hydrodynamical-thermodynamical study of the factors which determined the broad features of the spectral distribution of the atmosphere's energy at the large-scale end which explained the quasi-geostrophic character of atmospheric motions. He also worked on a study of troposphere-stratosphere energy propagation by calculating the "optics" of refraction and

reflection of long atmosphere waves. In his work on the geostrophic approximation, Charney found that it was better to consider the horizontal wind as approximately non-divergent in the potential vorticity equation. Eady investigated criteria for the stability of a baroclinic zonal current. With the exception of very long wave lengths, Eady's criteria agreed with Charney's as long as the variation of the Coriolis parameter and an infinitely vertical atmosphere were included. Very long wave lengths, however, became unstable. Eady also studied the stability of barotropic shearing flow and baroclinic flows with a combined horizontal and vertical shear. Fjörtoft showed that repeated space smoothings could be successfully applied to the solutions of general elliptic equations. He also was continuing studies on improving the geostrophic assumption.[94]

As the time approached for the JNWPU to come on-line, the Princeton group was rapidly debugging the operational models. However, its work was not complete. There was still much to be discovered about atmospheric circulation, and there was much work left to be done before longer range forecasts would be viable. As NWP became operational, the Meteorology Project would just shift its focus back to more theoretical issues.

The move to operational NWP was not restricted to the United States. During the year preceding the opening of the JNWPU, other centers of activity were gaining ground in Europe and were pushing towards their own operational forecasting units. By late 1953, the Stockholm group was very busy on BESK. According to Phillips, it had been running quite well. With the exception of output (i.e., the actual printed result), BESK was faster than the IAS machine. Rossby's team members had made three 24-hour barotropic forecasts using a 20x20 grid – the maximum size possible due to the 512 word memory. They were awaiting the installation of the magnetic drum which would allow them to increase the grid size to 31x55, 31x32 and 31x22 for the one-, two- and three-layer models respectively. The Stockholm group planned to concentrate on longer period forecasts in the future.[95]

In late October/early November 1953, Thompson made another European tour to assess the progress of numerical weather prediction in Sweden, West Germany, and the United Kingdom. After returning to the United States, he reported that the Europeans were about six months behind in basic theory and one to two years behind in operational application due to personnel shortages, lack of training, and non-availability of especially dedicated computers for numerical weather prediction. Deutscher Wetterdienst was working on putting NWP into operation, but it did not appear that they could do so before early 1956. The British Meteorological Office intended to fold numerical techniques into their forecasting practice, but without a computer would be limited in what it could do. Rossby's group "professed to have no definite plans for operational applications, but have the capabilities for putting numerical methods into practice by early 1955." Since the Swedish team in fact began producing operational forecasts in 1954, it appears that Thompson was somewhat led astray by what he heard in Sweden. Thompson was authorized to offer Rossby the possibility of an Air Force contract for research. Rossby was glad to take it but reminded Thompson that, because Sweden was a neutral country, the funds would need to be "decontaminated" via a civilian

[94] The Institute for Advanced Study, Meteorology Project, Progress Report July 1, 1953 to March 31, 1954, Contract No. N-6-ori-139 (1), NR 082-008 (Charney papers, B9, F305).

[95] Phillips to Charney, 19 December 1953 (Charney papers, B14, F449).

institution, e.g., Woods Hole Oceanographic Institution.[96]

In early spring 1954, Smagorinsky went to Europe and then reported that the British and the Swedes anticipated making daily operational predictions within six months.[97] It happened sooner than that. In mid-June, Rossby informed Charney that the Stockholm team had made 23 barotropic forecasts for the eastern Atlantic and northern Europe, including two operational ones, on BESK. Having gotten good results, they were preparing to make operational 48-hour forecasts.[98] In contrast, the JNWPU's computer would not be available for six more months.

4.4 THE JOINT UNIT COMES TO LIFE

After over a year of planning and negotiations, the Joint Numerical Weather Prediction Unit became a non-operational reality on 1 July 1954. It was non-operational because it had no computer and would not have one for at least six more months. However, its personnel still had plenty of work to accomplish. Cressman laid down four primary tasks for his Unit: evaluating which model would be best for initial operational use, preparing a program library, training personnel to program the computer, and training the analysts.

The JNWPU worked closely with both GRD (the Numerical Prediction Project under Thompson) and IAS to evaluate models. Both IAS and GRD ran their three most promising models from the same initial data and compared the output. JNWPU members planned to obtain time on IBM's New York-based 701 to run some of the programs. They anticipated running the three models based on thirty different starting maps by 1 February 1955. After studying approximately sixty baroclinic forecasts made by the GRD, the JNWPU's Development Section discovered that half of the systematic errors could be attributed to neglecting terrain-induced vertical motions. It was also analyzing the effects of ignoring some of the terms in the vorticity equation. Another study dealt with erroneous boundary assumptions and how they affected model output. However, sixteen of the sixty 500 mb height forecasts were found to be significantly more accurate than the subjective maps obtained from the USAF Weather Central for the same verifying times. Based on these findings, the Development Section members had revised models and they were being tested by both hand and machine computation at IAS. The Computing Section was working on a number of different programs including barotropic, three-parameter baroclinic with terrain, objective analysis, three-parameter baroclinic for comparison testing, two-parameter baroclinic programs, and a program which would give a baroclinic forecast with boundary conditions given by a barotropic forecast covering a larger area. Unit members who reported in July attended an IBM-provided programming course. IBM would provide a similar course in the fall for those arriving later.[99]

With the JNWPU officially open for business, the work of the Ad Hoc Group was done. However, an oversight committee still needed to be formed to provide assistance and work out problems between the three

[96] Thompson to Chief, Atmospheric Analysis Laboratory, ca. November 1953 (Philip D. Thompson papers, National Center for Atmospheric Research Archives, Correspondence 1953-1954) [Hereafter **Thompson papers**].

[97] JCS/JMC Ad Hoc Group for Establishment of a JNWPU: Minutes of the 11th Meeting held on 11 March 1954 (JNWP-16-54) (Wexler papers, B32, NWP).

[98] Rossby to Charney, 16 June 1954 (Charney papers, B14, F460).

[99] Activities of the Joint Numerical Weather Prediction Unit, 1 July to 1 October 1954 (Wexler papers, B32, NWP).

contributing weather services. Therefore, on 4 November 1954, the JMC formally dissolved the Ad Hoc Group and established yet another *ad hoc* committee: The Ad Hoc Committee on Numerical Weather Prediction (JMC/NWP).[100] Under the "Terms of Reference," i.e., the description of its tasks and responsibilities, each weather service was authorized to appoint one member to the Committee although others would be allowed to attend meetings in an advisory capacity. The JMC/NWP would stay cognizant of the workings of the JNWPU, assist and advise its Director on requirements, external technical matters, fiscal issues, service personnel issues, and off-time usage of equipment. The JMC/NWP would keep the JMC informed of NWP matters and bring any major policy issues to it for resolution. However, it was not within the purview of the Committee to solve any highly technical problems. For those, the Cressman could seek the advice of scientific consultants after receiving the concurrence of the Committee members. This quasi-supervisory role of the Ad Hoc Committee did not give it license to be a micro-manager. Since the Unit was a new entity in a new field, the Director was to have wide latitude in determining what should be done.[101]

One of the first issues, not surprisingly, dealt with personnel. The Navy representative (Captain Oberholtzer) made clear that all Navy personnel assigned to the Unit must be trained in each of its primary functions, i.e., modeling, programming, and analysis. Cressman indicated that personnel would be cross-trained to the extent that there was a fit between their background and their desires, but that some personnel did not want to perform some of the functions of the Unit. This likely sent Oberholtzer over the edge, as it pointed to a tremendous gulf between the culture of civilian meteorologists and the military services: in the Navy, one's individual "desires" had nothing to do with one's assignment to a task. In response to a question by Wexler, Cressman stated that all of the analysts were taking the [machine] coding course and that everyone would be involved in discussions of all aspects of the program. Service representatives would share information about the qualifications of incoming personnel directly with Cressman. Cressman would handle unsuccessful assignments with the appropriate service representative.

Cressman had already made the necessary contacts to secure technical consultants before the terms of reference were issued. Consultants from outside government included Charney, Gilchrist, and Bigelow from IAS, Platzman from the University of Chicago, and Rossby from the University of Stockholm, Sweden. Thus, after over nine years of helping to coordinate the development of numerical weather prediction, Rossby finally had an official role. Consultants from within the government service included computer specialists Lawrence Gates (GRD), von Neumann (AEC), and Franz Alt (National Bureau of Standards).

Any agency desiring to place new requirements on the JNWPU had to coordinate them through JMC/NWP. Without this provision, there would have been chaos almost immediately. The Air Force, Navy, and Weather Bureau each had different mission requirements. Each would

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[100] The original members JMC/NWP were Captain W. E Oberholtzer, Jr., USN, Lt. Colonel H. H. Bedke, USAF, and Dr. H. Wexler, U.S. Weather Bureau.

[101] Terms of Reference, Joint Meteorological Committee, Ad Hoc Committee on Numerical Weather Prediction (JMC/NWP), Enclosure to Memorandum for the Members, Joint Meteorological Committee (JMC-130-54) of 10 November 1954 (Weather Bureau papers, National Archives and Records Administration II, College Park, Maryland, RG 27, JCS/JMC) [Hereafter **Weather Bureau papers**].

be seeking different products from the Joint Unit. Without a clearing house for their specialized mission requirements, the Unit would be overwhelmed with requests. As far as requirements being levied *by* the Unit, Cressman reported that the WBAN Analysis Center would be plotting and analyzing two 400 mb charts per day starting in January 1955. Because the analysis section of the JNWPU had been kept small on purpose, he was counting on WBAN to fill its needs. Due to the coordination required between JNWPU and WBAN, the Ad Hoc Committee determined that the Joint Unit would need to be able to deal directly with the Coordinating Committee of the National Weather Analysis Center (WNAC – the replacement for the WBAN Analysis Center) if and when such a committee was established under the JMC.

Another important issue was the policy for "outside use" of the IBM 701. The machine had not yet arrived, but outside agencies were already seeking computer time. Under the terms of the proposed policy, the machine could be used by either governmental meteorological services or cooperating NWP research groups subject to the Director's approval of the problem to be run on the computer. Any use of the computer had to be at the convenience of the Unit, and the Unit would provide no manpower assistance with the exception of the machine operator. Any non-governmental groups using the machine would be expected to pay for all machine time unless there was a reciprocal arrangement on another machine. When Wexler questioned why the JNWPU needed to be reimbursed, when the machine time was already paid for, Cressman commented that they wanted to discourage non-meteorological organizations from using the machine.[102] Discussion also revolved around who would be allowed to submit programs to run on the machine. The Air Force representative thought the first priority should go to whatever group had the most to contribute to NWP regardless of whether they were a governmental agency or an NWP research group. As far as reciprocal computer time, Cressman noted that both the GRD and IAS had run programs for the JNWPU, and therefore the Joint Unit should run programs for them if asked. The other issue was machine time outside of the time already contracted for with IBM. Once those hours were exceeded, then the cost increased. Therefore it was decided that as much as possible, any requests for time would have to fit into the time for which IBM had already been paid.[103]

Since the beginning of fiscal year 1956 was only six months away (it would start 1 July 1955), the Committee considered its budget needs. Cressman anticipated no further staff increases after fiscal year 1956. He thought he might even be able to reduce staffing by one plotter. By the five year point, it might be possible to reduce the programming staff. Apparently, Cressman thought that once they had the models programmed they were home free and would do very little programming work. His casual comment shows a consequence of a complete lack of experience in the field – no fault of Cressman, everyone was new to the field – and yet it defies common sense. The purpose of this Unit was to take upgraded models and put them to operational use. The programming would always need to be done in-house. Therefore, the number of programmers would not decrease with time

[102] JMC/NWP Minutes of 1st Meeting held 29 November 1954 (Weather Bureau papers, RG 27, JCS/JMC).

[103] JMC/NWP Minutes of 2nd Meeting of 13 December 1954 (Weather Bureau papers, RG 27, JCS/JMC).

unless no improvements were made to the models. The whole idea behind making the transition from a research to an operational organization was to insure that model improvements took place faster. Decreasing the numbers of programmers would probably cause modeling to stagnate instead. The anticipated contribution of each service for fiscal year 1956 was approximately $205,000. The Air Force representative advised that his service would need an estimated fiscal year 1957 budget not later than January 1955 (fiscal year 1957 would have started on 1 July 1956).[104] It is somewhat surprising that the military members were not pushing for budget estimates for years even further out. (Generally, budgets were set up in five year cycles and then readjusted each year as the operational climate changed.)

JMC members addressed the coordination problem with the new National Weather Analysis Center (NWAC) in late 1954. Whereas the WBAN Analysis Center had fallen under the supervision of the ACC/MET, the new analysis center would be without JMC supervision if a new *ad hoc* committee were not established to fill that role. The JMC expected that analysis center would be operational in January 1955. If no action were taken, JMC would no longer have a supervisory role. On the other hand, the Joint Unit fell under the cognizance of the JMC via the *ad hoc* group. That meant the Unit could not directly approach the analysis center for assistance – it had to follow a cumbersome, circuitous chain through advisory committees *up* to JMC and then *down* to the analysis center. This was clearly a problem. Since JMC had discussed merging the Joint Unit and the analysis center, members suggested that the JNWPU be placed under ACC/MET and the *ad hoc* group dissolved.[105] This issue was discussed again a few weeks later. The requirement for the analysis center to produce 400 mb charts for the Joint Unit was sent by the JMC to ACC/MET. Then JMC members addressed the issue of weather service coordination. The question: who should have supervisory authority over the Joint Unit and the analysis center? Even though the Weather Bureau argued that there was no reason for the JNWPU to be under JMC supervision, all agreed that the best scenario was for both units to be supervised by ACC/MET once they were operational. Since neither was operational, it was not yet an issue. In response to the Weather Bureau's comment about JMC supervision, the Air Force pointed out that it received part of its budgetary support for the Joint Unit by virtue of its association with the JMC. The Weather Bureau argued that unless it was absolutely necessary, no committees should supervise either unit because as Reichelderfer put it, "committee operation of a unit is never good." Undoubtedly part of Reichelderfer's motivation was due to the fact that both of these units resided in Weather Bureau spaces and were under the Weather Bureau's administrative control despite being jointly funded and staffed. The military units were probably concerned with losing any kind of control within a civilian organization without the JMC related supervision.

The JMC discussed the use of computer time by outside agencies and concurred in the policy as proposed by the *ad hoc* group. The JMC also brought up the fiscal year 1956 budget, but both military representatives asked for a deferral until they could study it. All agreed that they

[104] JMC/NWP Minutes of 1st Meeting held 29 November 1954 (Wexler papers, B32, NWP).

[105] JMC 60/15.5; Joint Meteorological Committee, Coordination Between the Joint Numerical Weather Prediction Unit and the National Weather Analysis Center, 16 December 1954 (Weather Bureau papers, RG 27, JCS/JMC).

strongly supported the Joint Unit and did not anticipate a problem with their share of the budget.[106] However, by the middle of January, funding and manpower problems were beginning to appear. The Air Force could not meet the manpower requirements, but could substitute funds for manpower even though it was not sure it would have its full share to offer. Although Weather Bureau leaders wholeheartedly supported the NWP effort, high authority had eliminated the money the Bureau had set aside for the Unit. However, the Bureau continued to seek funding for its full share. The Navy reported that only part of its share had been included in its budget. That was partly due to the sharp increase in the Unit's budget between fiscal years 1955 and 1956, as it moved from the pre-operational to the operational stage. The Navy needed to wait until the entire military budget had been adopted before knowing if there would be additional funds. The JMC then approved the proposed fiscal year 1956 budget with the stipulation that it would await the outcome of the total budgets of the Departments of Defense and Commerce.[107]

Cressman briefed the JMC on the status of the Joint Unit on 3 May 1955. The IBM 701 had been checked out and accepted from IBM two months earlier. In mid-April, Unit members had run the first experimental forecasts. The results had been better than anticipated. Since the computer had arrived later than expected, Unit personnel would not complete the shakedown phase (Phase I) until 6 May 1955. At that time, Unit members anticipated the beginning of Phase II operations. During Phase II, they would extend the objective analysis for North America approximately 1500 miles into the North Pacific and North Atlantic. This analysis would be for internal JNWPU use only. Unit members would also produce a baroclinic three-level prognostic chart for the United States. Problems with the introduction of terrain effects had led to some programming difficulties, but Unit members expected to overcome those within a couple of weeks. They would also be producing vertical motion products between the 900 mb (1000 meters/3300 feet) and 700 mb (2700 meters/9000 feet) layers and the 700 mb and 500 mb (5500 meters/18,000 feet) layers at 12-hour intervals. The baroclinic and vertical velocity products would be available for users starting on 6 May. Work continued on a barotropic 500 mb prognostic chart covering all of the Northern Hemisphere.

The relative accuracy of the computer-generated charts generated a happy surprise for the Joint Unit. To "verify" the weather maps, Unit members checked the 24-hour computer produced prognoses at the three levels (400, 700, and 900 mb) by comparing the distance between the forecast and observed low height center positions. The 400 and 700 mb levels showed a difference of two degrees each of latitude and longitude, while the 900 mb level showed a two degree latitude and five degree longitude difference. (Each degree is approximately 65 miles.) These results were better, Cressman argued, than the best subjective efforts and should be considered to be the worst that could come out of the Unit. After all, this was an initial, experimental effort.

The handling of the incoming data for the objective analysis continued to be a major problem. The data came in via teletype and fifteen man-hours later Unit members had finished manually punching the data onto cards and feeding them into the machine. The Unit had obtained a machine

[106] Minutes of the Joint Meteorological Committee 340th Meeting held 21 December 1954 (Weather Bureau papers, RG 27, JCS/JMC).

[107] Minutes of the Joint Meteorological Committee 341st Meeting held 18 January 1955 (Weather Bureau papers, RG 27, JCS/JMC).

that would read the teletype paper tape and convert it automatically to punched cards. This new procedure would reduce the number of sub-professionals from five to one. The computer could then be programmed to sort through the observations and reject reports, which were either not needed for the objective analysis or which were garbled, before running the program. Cressman noted that automated data handling was just beginning and it would be a number of months before this would become a routine operation.

The teletype system, sufficient for subjective methods, was also a problem. It took nine hours just to collect all the data needed for a single chart. If the observation and transmission schedules were changed, it would only take thirty minutes. Considering the amount of time that it took to tear teletype tape and punch cards plus the time to run the programs, it was apparent that the nine hours being absorbed by data collection would need to be dramatically reduced if the numerical prediction runs were to work.

As an example of the military influence on the Unit's work, prognoses were being created for the 500 mb level. This was an obvious level to try out first since it represented the "steering level" for surface systems and thus was highly valuable for forecasters. It was also used because that was the level flown by Air Force Weather Reconnaissance Aircraft. However, the Air Force was thinking of moving those flights to a higher level (400 mb) which could potentially impact the desirability of creating the 500 mb charts. The aircraft reports were used as input and verification tools. Changing the level could influence the operation of the Unit.

Cressman also wanted more data from over the Pacific. As a trial, the Weather Bureau had put an upper air team aboard USNS *General Hugh J. Gaffey* (a Military Sealift transport ship) while underway in the Pacific, and had obtained excellent results. The regular availability of such soundings from ocean areas would help to anchor the forecast. Another possibility: use dropsondes launched from aircraft transiting the area.[108] However, both of these were very expensive options, and if the Weather Bureau leaders were worried about having enough money to keep the Unit operational, they probably did not have enough money to send upper air teams out to ride ships-of-opportunity, i.e., ships transiting the area that were willing and able to take on men and material, or to send dropsondes out with military planes flying across the ocean.

4.5 AT LONG LAST – DEDICATION

The shakedown period of Phase I was over for the JNWPU. Unit members had checked out the computer, the personnel were on board, the model was running, and communications circuits were in place. The time had come for numerical weather prediction to leap beyond the experimental and into operation.

The dedication ceremony took place on 6 May 1955 – almost nine years to the day of the time IAS had sent its proposal for a Meteorology Project to ONR. In the Weather Bureau's remarks prepared for that day, tribute was paid to the pioneers of hardware development, upper air investigations, dynamic meteorology, and, of course, to L. F. Richardson who in 1922 published the disastrous results of his attempt at numerical weather prediction. And credit was given to von Neumann and Charney for their leadership in the Computer and Meteorology projects and for bringing to fruition two of the three legs on which numerical weather prediction stood: the electronic computer and meteorological

[108] Minutes of the 344th meeting of the JMC held 3 May 1955 (Weather Bureau papers, RG 27, JCS/JMC).

theory of large-scale atmospheric motions. The third leg – a sufficient density of upper air observations – was in place as a result of World War II. Credit was also given to Air Force, Navy and Weather Bureau personnel who had been critical to the development and planning of this "unprecedented venture." Absent was any mention of the tag-team of European meteorologists – primarily Scandinavians and Britons – who had bailed the Meteorology Project out of numerous manpower holes. These meteorologists, who had stayed in the United States for several months to a year at a time, had been crucial to creating the dynamic-synoptic meteorology interface required for the successful creation of numerical weather prediction models.

The speaker emphasized that the "new era in meteorology" that provided these computer products was not an excuse to "sit back and take it easy." On the contrary, forecasters would now have more time to devote to their local forecasts, with the computer taking care of the large-scale forecast. Modeling results had revealed that topographic, coastal, and diurnal effects were more subtle than previously thought. This discovery would allow meteorologists to concentrate their efforts on other elements that might ultimately be more important to solving the forecasting problem. The computer "under intelligent human direction" would be the forecaster's assistant – not the controlling factor in making forecasts.[109]

5. CONCLUSION

And so it was. Or was it? Of course those early computer runs couldn't really compete with the subjective charts being transmitted via landline and fax machines to Weather Bureau, Navy and Air Force stations all over the United States. But they were a very important start. With each generation of computer and each improvement to the models, subjective methods continued to drop away. Numerical weather prediction became an important part of the atmospheric sciences curriculum. Forecasters, who often grumbled about models flaws, grumbled even louder when model output did not flow in on time. Over 50 years later, the most powerful computers in the world run atmospheric models – and no one suggests that NCEP might want to share its computers with the Bureau of the Census.

[109] "Suggested Remarks for Mr. Little at the Joint Numerical Weather Prediction Unit Opening Ceremony May 6, 1955," 4 May 1955 (Francis W. Reichelderfer papers, Library of Congress, Manuscript Division, B2, F10).

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